INSTRUCTION MANUAL
FOR
DANA* SERIES 3400
DATA AMPLIFIERS

DANA

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INSTRUCTION MANUAL
FOR
DANA* SERIES 3400

DATA AMPLIFIERS

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SPECIFICATIONS

All specifications apply for 0 to 350 ohm signal sources, in any unbalance	Model 3400	Model 3420
OUTPUT		
Full scale voltage	± 10 volts	± 10 volts
Over range, nominal	20%	20%
Full scale load current	10 ma	100 ma
Impedance	250 milliohms	100 milliohms
Capacitive load, without instability	.05 mfd	.5 mfd
SHORT CIRCUIT PROTECTION		
Fail-safe circuit prevents damage, allows immediate recovery; approximate current with short or excessive load	15 ma	150 ma
FREQUENCY RESPONSE		
DC to 100 cps, full amplitude	± 0.01%	± 0.01%
DC to 20 kc, full amplitude	± 1 db	± 1 db
DC to 50 kc, 10% amplitude	± 3 db	± 3 db
LINEARITY		
DC	± 0.01%	± 0.01%
AC to 2 kc	± 0.01%	± 0.01%
COMMON MODE REJECTION		
DC to 60 cps, 10 volts dc or peak ac with gain of 1000 (up to 60 volts without damage)	120 db	120 db
NOISE REFERRED TO INPUT AT GAIN OF 1000		
50 kc bandwidth	4 uv rms	4 uv rms
100 cps bandwidth	2 uv P to P	2 uv P to P
STEP FUNCTION SETTLING TIME		
To final value ± 0.1% of full scale	250 usec	250 usec
OVERLOAD RECOVERY		
To final value ± .1% of full scale ± 10 uv referred to input		
From 500% overload of any duration	2 ms	2 ms
From 10V overload of any duration (no damage from 30V overload)	10 ms	10 ms
ZERO DRIFT		
Constant temperature, 200 hours	± 0.02%	± 0.02%
Per degree C, Referred to output ± 1 uv referred to input	100 uv	100 uv

GAIN OPTIONS Without Mulitplier	With X.01 Mulitplier
OPTION F-1 30, 100, 300, 1000 with single vernier for ± 2% adjustment. Gain resolution and stability ± 0.01%	None provided
OPTION F-2 * 30, 100, 300, 1000 with single vernier for ± 2% adjustment. Gain resolution and stability ± 0.01%	0.3, 1.0, 3, 10 with single vernier for ± 2% adjustment. Gain resolution and stability ± 0.01%
OPTION V-1 20, 50, 100, 200, 500, 1000 Gain accuracy ± 0.1%, stability ± 0.01% with vernier to provide any gain between 20 and 2500. Resolution and stability ± 0.01% (low end) ± 0.1% (worst case)	None provided
OPTION V-2 * 20, 50, 100, 200, 500, 1000 Gain accuracy ± 0.1%, stability ± 0.01% with vernier to provide any gain between 0.2 and 2500. Resolution and stability ± 0.01% (low end) ± 0.1% (worst case)	0.2, 0.5, 1.0, 2, 5, 10. Gain accuracy ± 0.1%, stability ± 0.01% with vernier to provide any gain between 0.2 and 2500. Resolution and stability ± 0.01% (low end) ± 0.1% (worst case)

* For F2 gains below 30 and V2 gains below 20; frequency response is ± 1 db to 10 kc; common mode rejection 66 db, dc to 60 cps up to ± 250V dc or peak ac; input impedance 1 megohm either input to output common; zero drift/C° 100 uv referred to output ± 500 uv referred to input.

TEMPERATURE RANGE		
Operating, in degrees C	0° - 50°	0° - 50°
Storage, in degrees C	-20° to 85°	-20° to 85°
INPUT IMPEDANCE	10 megohms	10 megohms
POWER REQUIREMENTS		
105 to 125 volts rms, 50 to 400 cps .	4 watts	6 watts
UNITS PER ENCLOSURE	10	5
ENCLOSURE MODEL	Model 3010	Model 3005
WEIGHT	3 lbs	5 lbs

2. DESCRIPTION

The Dana Data Amplifier (Figure 2.1) is an all solid state, wideband, differential, low-level dc amplifier with integral power supply.

The unit is designed for general use in test instrumentation and data acquisition systems. It is suitable as a preamplifier for analog magnetic tape or oscillographic recorders as well as Digital Systems. Models with dual outputs can work simultaneously with both wideband recorders and digital systems.

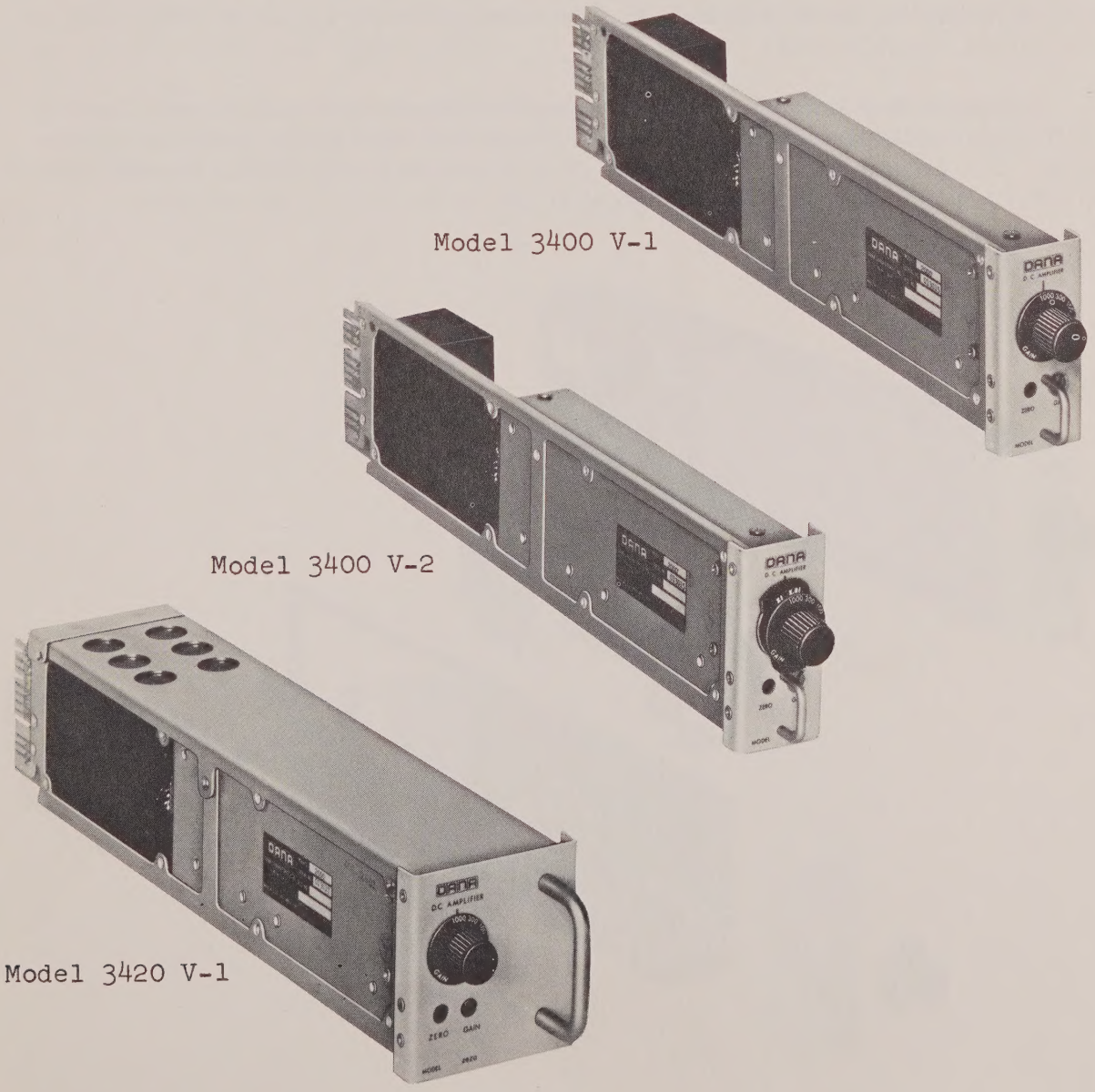


FIGURE 2.1. External Three-Quarter View

The first general purpose instrument of its type, the Dana Amplifier may be used as either a differential or single-ended amplifier. In the latter case, no special plug-ins or switches are required. Wide bandwidth, fast settling time, and high common-mode rejection add to its versatility.

The amplifier features excellent linearity, high gain accuracy, low drift and low noise.

Extreme reliability and long life stem from the basic design. Mechanical choppers and other moving parts have been eliminated. New design concepts have resulted in simplified circuits that minimize the total number of components. Silicon semiconductors are used exclusively. The internal circuitry is contained on removable printed circuit boards.

There are five front panel controls used in operation: a gain selector switch, a X.01 gain multiplier, a bandwidth selector and two recessed screwdriver adjustments. One adjustment is for zero; the other a vernier gain control. Certain models are not equipped with the bandwidth control and/or the X.01 gain multiplier.

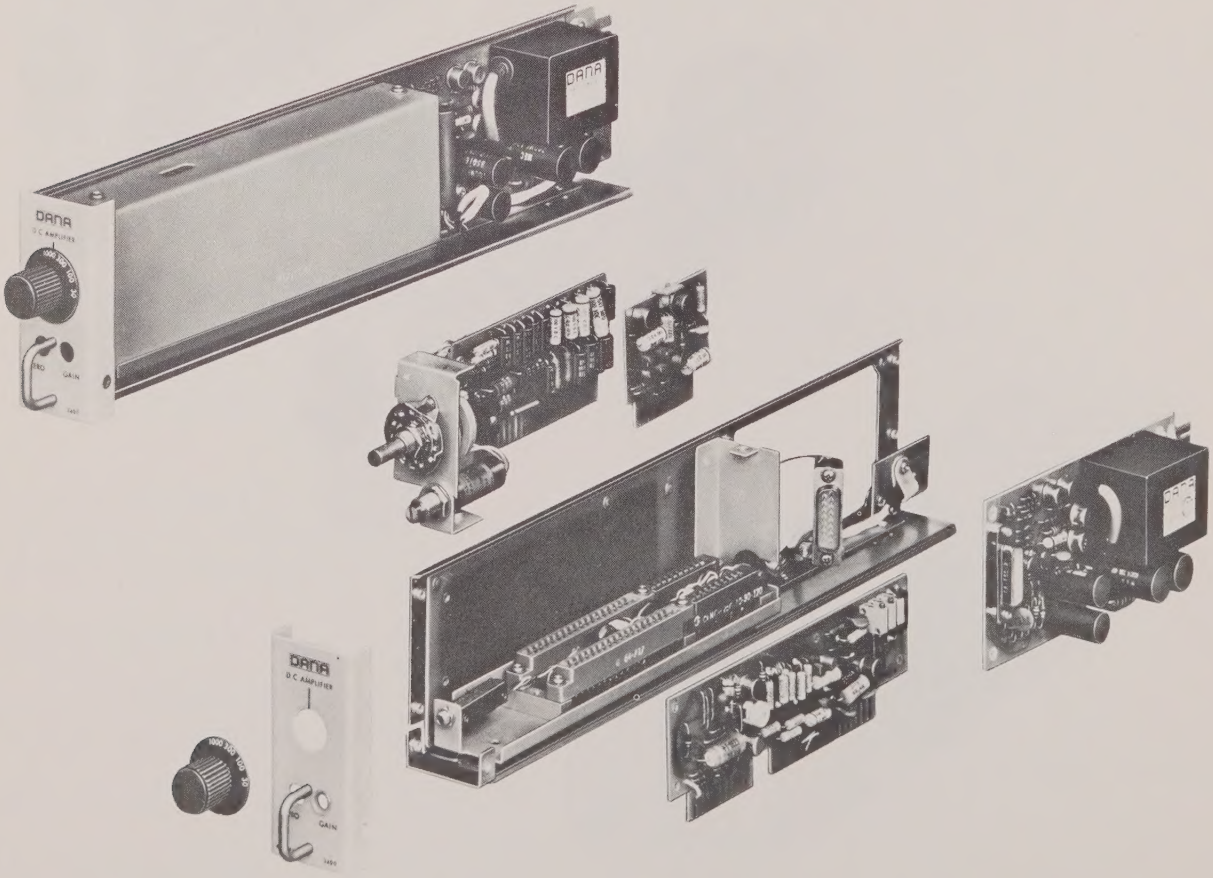


FIGURE 2.2 . Exploded View

3. UNPACKING AND INSPECTION

The Dana Amplifier is shipped in a special reusable shipping pack, designed to protect the instrument from excessive shock and vibration.

Examine the package for signs of external damage before removing the unit. If external damage is present, notify the carrier before proceeding.

Next, examine the outside of the amplifier for any evidence of damage due to excessive shock, vibration, water leakage, etc. If there is no visual external damage, remove from the enclosure and check physical condition of the circuit boards and components.

If the unit appears in perfect condition, perform the checkout operation described in Section 4. However, if there is any apparent damage communicate with the carrier for instructions.

4. INITIAL CHECKOUT AND OPERATION

4.1 GENERAL PROCEDURE

The simple tests described in this section are generally sufficient to check out the instrument on receipt. The purpose of these tests is only to establish that the amplifier is in operating condition. The procedure should not be confused with the more elaborate specification checks which the user may want to perform before he actually puts the amplifier into use.

a) Power Connections

All amplifiers have self-contained power supplies which are operated from the ac line. Single-phase, 115v rms, 50 to 400 cps power is required. A three-wire line cord should be used with a standard three-prong connector. The third wire is used to ground shields internal to the power supplies. The line cord should be connected to the amplifier connector as shown in Figure 4.1. Do not apply power until all other elements in the test setup are connected. If the unit is to be operated on the bench, care must be taken to see that the mating connector is properly keyed. If the ends of the mating connector are inverted, severe damage can be inflicted to the amplifier.

A - NOT USED
B - AC POWER
C - AC POWER
D - AC POWER GROUND
E - NOT USED
F - OUTPUT COMMON (wideband)
H - OUTPUT (wideband)
* J - OUTPUT COMMON (optional Variband)
* K - OUTPUT (optional Variband)
L - DO NOT USE
M - INPUT GUARD
N - INPUT SIGNAL
P - INPUT SIGNAL
R - DO NOT USE
S - DO NOT USE

* Open on Model 3400, and
Jumpered to wideband output lines on Model 3420

FIGURE 4.1 - Connector Designations

b) Input Terminals

The input consists of two terminals, one marked N, the other marked P. In most applications, the leads to these terminals must be guarded electrostatically by an isolated and insulated shield. However, it is not necessary to provide such a shield to conduct the following check-out tests.

c) Output Terminals

The primary output consists of two terminals. One is the output (H), the other is the Output Common (F). For these tests, the common terminal should be tied to the low side of all test equipment and returned to power line ground. If the amplifier under test provides two outputs, the common terminal of the second output (J) should be tied to (F). Tests on both outputs can then be conducted by switching the oscilloscope between output terminals (H) and (K). Figure 4.1 defines these two output terminals.

Only three pieces of test equipment are required to conduct checkout tests:

Audio Oscillator
Voltage Divider/Attenuator
Oscilloscope

Standard laboratory-type instruments from any manufacturer may be used.

4.2 GAIN

The Dana unit is designed as a differential amplifier, but it may also be operated as a single-ended amplifier. For the sake of simplicity, basic gain and frequency response checks are made in the single-ended, noninverting mode.

First step is to ground the oscillator, voltage divider, oscilloscope and amplifier COMMON (both commons for dual output amplifiers). To accomplish this, connect the common or ground terminal of each instrument to a single point, then connect this point to ground. All measurements are made relative to this point.

Next, connect the oscillator output to the input of the voltage divider. Then connect the output of the divider to the amplifier input P lead. The N lead is connected to either the ground point or the lower terminal of the voltage divider. Connect the amplifier wideband OUTPUT to the oscilloscope input. (Set single output "variband" models to maximum bandwidth).

Set the voltage divider to minimum output, zero if possible. Then plug the amplifier into the power source.

The output from the amplifier, as indicated by the oscilloscope trace, should be within a few millivolts of ground, and should change only very slightly as the gain setting on the front of the amplifier is changed. If the amplifier has a gain multiplying vernier, turn the screwdriver adjustment to minimum (extreme counter-clockwise). Then set the gain knob at maximum. If the unit has an X1, X.01 gain multiplier, set to X1.0.

Disconnect the oscilloscope input from the amplifier OUTPUT and connect the oscilloscope to the oscillator output. Adjust the oscillator to 20 volts, peak to peak at 100 cps or any other convenient low frequency. Set the voltage divider at the reciprocal of the maximum amplifier gain setting, or 1/K. Now return the oscilloscope input to the amplifier OUTPUT. The oscilloscope should indicate approximately the same value, 20 volts, as when connected directly to the oscillator. The term "approximately" is used because of limited capability of an oscilloscope to compare two magnitudes accurately.

There should be no obvious noise or other unexplained distortions in the oscilloscope trace.

4.3 FREQUENCY RESPONSE

Change the oscillator frequency to 20,000 cps and repeat the procedure outlined above.

There should be only a slight change in the comparable gain. Adjust the voltage divider until an identical magnitude displayed by the oscilloscope is observed. The difference in the voltage divider setting, compared to that of the low frequency test, should be no more than ± 1 db, or approximately 10%.

4.4 DUAL OUTPUT MODELS

The second output of dual output amplifiers should be observed while repeating the tests set forth in paragraphs 4.2 and 4.3. In addition, the Variband amplifier should be tested in accordance with paragraph 4.5.

4.5 MODELS WITH VARIABLE BANDWIDTH

Observing the Variband output, check the frequency response on each of the bandwidth settings provided on the front panel. Response should be -6 db ± 1 db at cutoff frequency, decreasing at 12 db/octave at higher frequencies.

4.6 COMMON MODE REJECTION

Short the amplifier leads, N and P, along with the input lead guard. Connect all three to the oscillator output. Connect the oscilloscope input to the amplifier OUTPUT.

Set the oscillator output to ten volts, peak to peak, at 60 cps. Set the amplifier gain at maximum as previously.

The common mode rejection in this case may be calculated as follows:

$$CMR = \frac{10 \text{ volts} \times K}{\text{OUTPUT Voltage}}$$

If the amplifier is operating at its normal common mode rejection, the output due to common mode will not be detectable above the wideband noise of the amplifier. A closer check would require a low pass filter between the output and the oscilloscope. (See Page 8.2 for test setup).

4.7 EVALUATION OF RESULTS

If the amplifier passes these simple tests, it is highly probable that it is fully functional. A complete and critical test of each amplifier is made prior to shipment. The sort of damage that can be expected in shipment tends to produce gross malfunctions, not minor changes in such sensitive characteristics as gain accuracy, linearity or common mode rejection.

More complete and precise tests are described in Section 7 - Operating Characteristics and Application Notes.

5. INSTALLATION AND OPERATION

5.1 INSTALLATION

The amplifiers may be used singly or mounted in groups. Multiple unit enclosures are available in standard IEA dimensions to accommodate 4,5, or 10 amplifiers. See the individual model specifications for complete dimensional data and the number of units per rack. Unused channels may be covered with Blank Panels. When operated near other power-dissipating instruments, forced air circulation may be needed as the amplifier should not be operated in ambient temperatures above 50^{o} C.

5.2 POWER REQUIREMENTS

The Dana amplifiers operate entirely off a single phase line voltage of 105-125 volts rms. Line frequency may range from 50 to 400 cps. The power requirements vary from 4 to 10 watts, depending on the model.

5.3 WARM UP TIME

Fully operational immediately -- zero stability achieved within 30 minutes.

5.4 INPUT AND OUTPUT CONNECTIONS

The physical forms of input and output connections are described in Section 4.1. For permanent installations, low thermal soldered connections should be used in the input connections. For temporary or test setups, screw terminals or clips of low ohmic resistance may be used, taking suitable care to minimize thermal emf's. (A few microvolts can be significant on high gain ranges).

The amplifier COMMON output leads should be directly connected to the input common or ground of the recorder, digital voltmeter or other output devices. The potential on this line may or may not be identical with that of the amplifier chassis itself. This is true even if the output device and the amplifier are mounted on the same rack. Care should be taken, therefore, to isolate the output leads as they leave the amplifier. If the amplifier has two outputs, neither of which is classified as an "isolated output", care should be taken to reduce the possibility of ground currents flowing between the two output devices through the output common lines. The N and P input leads should also be isolated. An insulated electrostatic guard should be used around the input leads and for maximum accuracy it should be connected through a low impedance path to the source of common mode voltage. A discussion of Common Mode Rejection versus accuracy is provided on Page 7.9.

Since the P and N inputs to the amplifier are symmetrical (both have nearly the same impedance to output common), either lead may be connected to either side of the signal source. For phasing purposes, if P is positive with respect to N, the output becomes positive with respect to output common.

5.5 SETTING THE GAIN

Gain is set by a front panel knob marked according to the Gain Option provided (see Section 1 - Specifications). Maximum output of the amplifier is 10 volts, with a nominal 20% overrange capability. No damage will occur to the amplifier, however, if an excessive gain is set, no matter what the duration. A current limiting feature serves to protect the recording device from excess current.

5.6 ZERO ADJUSTMENT

A screwdriver zero adjustment is accessible through the front panel. Before making this adjustment, energize the amplifier and any adjacent heat producing equipment and allow the amplifier to achieve thermal stability. Set the gain control to minimum, return the input leads to output common and adjust the zero control for minimum output. A counter-clockwise turn on the control will correct for a positive output; a clockwise turn will correct for a negative output.

5.7 BANDWIDTH

Certain models have active output filters with the bandwidth selectable by a front panel control. Operation of this control affects the "variband" output only.

6. THEORY OF OPERATION

6.1 INTRODUCTION

The Dana Data Amplifier is an all solid state, wideband, differential, low level dc amplifier with integral power supply. Direct coupled solid state circuitry with silicon transistors is used exclusively. Modulators, mechanical or otherwise, are not used.

6.2 OPERATIONAL DESCRIPTION

The basic amplifier is a four-terminal device (units with multiple outputs excepted) with two input lines and two output lines, one of which is referred to as "output common". Output signals are proportional to the electrical difference between the two input terminals, with potentials common to both inputs being rejected. Normal Mode Signals (also referred to as "Difference" or "Differential" Signals) and Common Mode signals are defined below.

$$\text{Normal Mode Signal} = E_1 - E_2$$

$$\text{Common Mode Signal} = \frac{E_1 + E_2}{2} \quad \text{(mid point between } E_1 \text{ and } E_2\text{)}$$

Figure 6.1 shows the amplifier responding to normal mode signals and rejecting the common component (one-half of the bridge supply voltage). In practical applications there would be additional common potentials due to stray fields and other causes. These potentials, represented by "E_x", are also rejected.

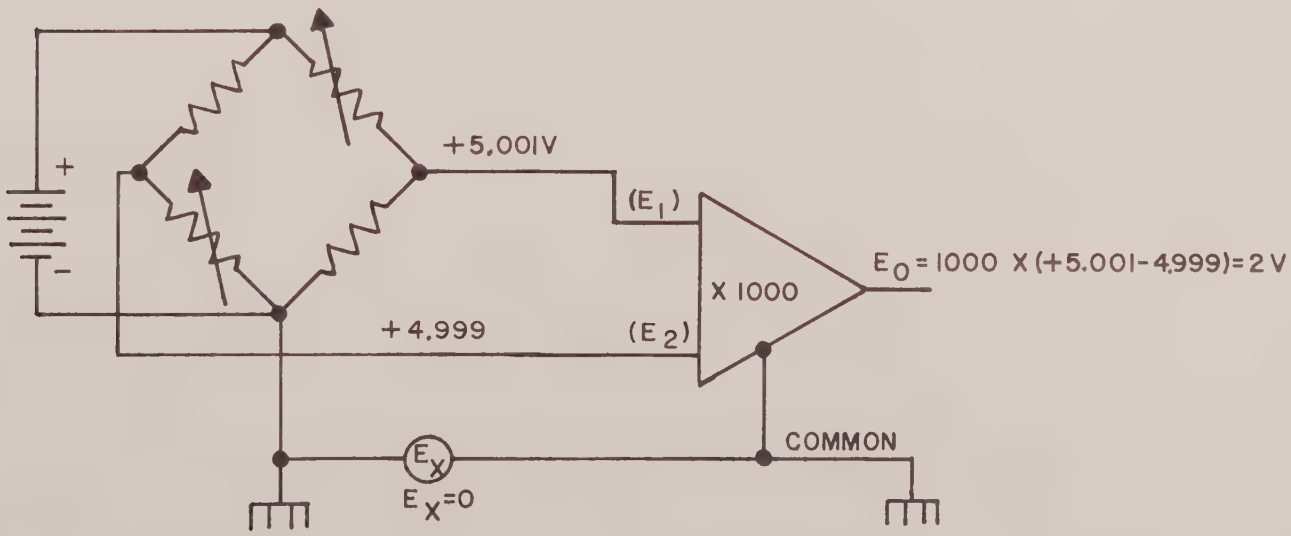


FIGURE 6.1 - Amplifier Responding to Normal Mode Signal and Rejecting Common Mode Potentials.

6.3 NORMAL MODE AMPLIFIER

The input stages, insofar as normal mode signals are concerned, are similar to conventional balanced differential circuits currently in common use; e.g., differential oscilloscope preamplifiers. The input lines are connected to the bases of a pair of matched silicon transistors (dual transistors in a single case) and the circuit parameters are adjusted to obtain equal characteristics in each stage. The only unique aspect of the circuit is the technique employed in controlling these parameters for stable operation over wide temperature ranges.

The outputs of the balanced differential stages are combined in a summing circuit which transfers one input directly and inverts the other, thus the differential response characteristic of "$E_1 - E_2$". Signals of common polarity or phase will cancel at the summing stage, the degree of cancellation dependent on their relative magnitudes.

Figure 6.2 is a simplified diagram of the input stages and summing circuit. For convenience of the initial presentation, the diagram has shown equal and opposite input signals which add at the summing stage. Later in the text, it will be shown that the amplifier will always have this signal symmetry internally, regardless of the symmetry of the input signal.

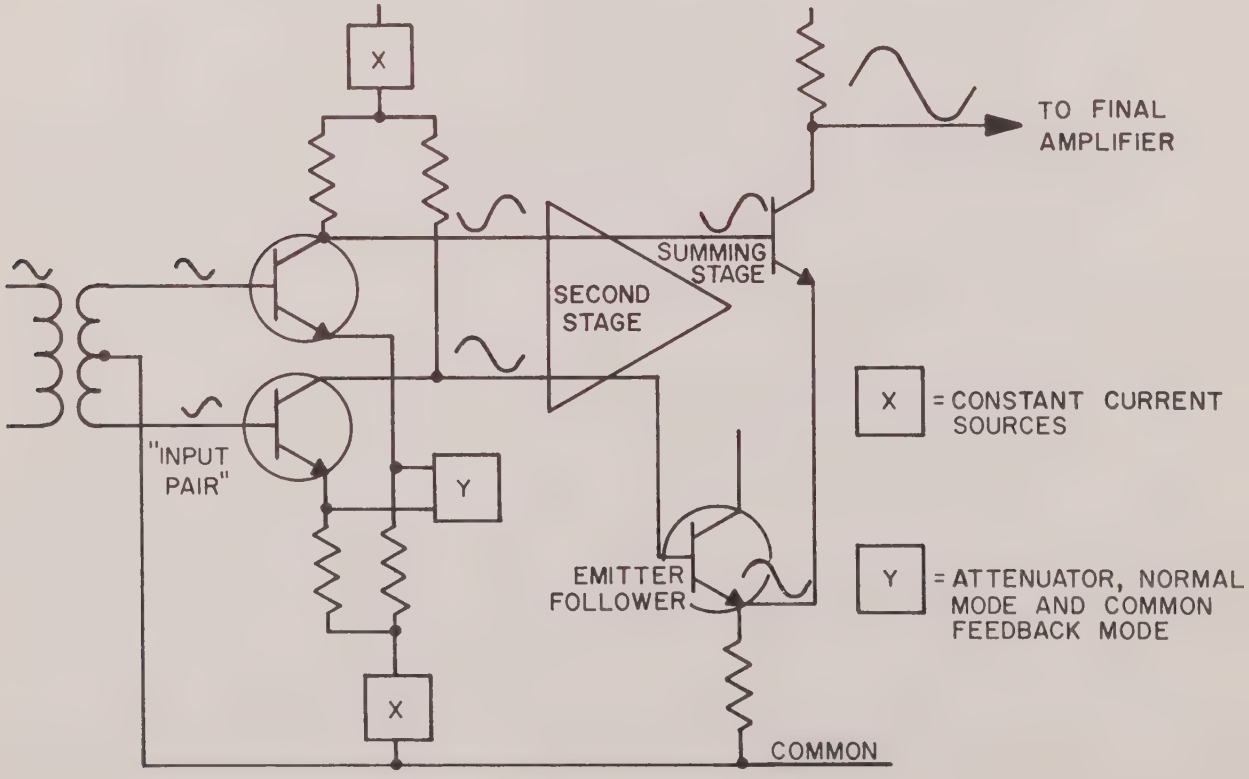


FIGURE 6.2 - Simplified Normal Mode Amplifier

The output of the summing stage is further amplified by the "main" or final amplifier with conventional direct coupled circuitry. The last stage provides a full scale output of ±10 volts. Output current capability varies with specific models and output options.

To achieve the desired gain stability and linearity, the open loop gain (gain without feedback) is considerably greater than the closed loop gain. By keeping this ratio sufficiently high, the "closed loop" or "net gain" is essentially determined by the feedback elements alone. Although the actual Dana amplifier has what might be termed a compound feedback network, it is similar in principle to the simplified circuit shown in Figure 6.3.

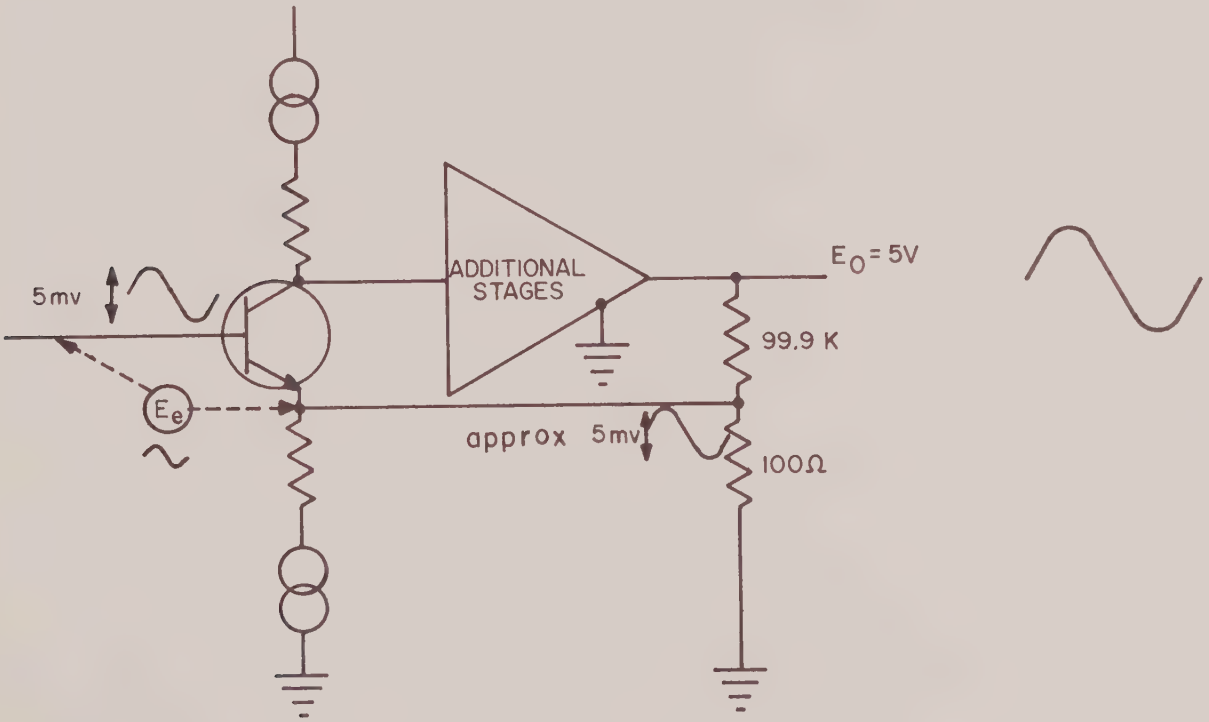


FIGURE 6.3 - A Simplified Potentiometric Amplifier (Gain of 1000)

Examining this feedback system, it can be seen that the feedback is of the proper phase to cancel the effect of the input signal; however, the cancellation leaves a small "error" signal of sufficient magnitude to support the 5 Volt output. In the example, if the open loop gain of the circuit were 140 db, the approximate residual error signal would be $5V/10^7$ or .5 uv (E_e in the diagram).

This type of amplifier is referred to as a potentiometric device, since the nature of the feedback achieves a high effective input impedance by the same basic principle as the common "battery potentiometer" approach to precision measurements. In both cases, the effective input impedance approaches infinity at null. In the case of the potentiometric amplifier, the impedance is limited by factors such as leakage and practical values of loop gain.

The actual circuit differs from the above example in that a more complex system of feedback is required for the differential amplifier involving the Common Mode Amplifier which is described below.

6.4 THE COMMON MODE AMPLIFIER

Although the basic Normal Mode Amplifier would provide a degree of Common Mode rejection (CMR = 60 to 70 db with balanced source), it would be insufficient for high accuracy data systems. The primary deficiency of this circuit is the low impedance between the input lines and common --- too low to materially reduce common mode currents. (See paragraph 7.12).

This deficiency is overcome by the use of a separate Common Mode amplifier (CMA) which senses the common mode voltage at the input and forces the emitters of the "input pair" to the same potential (neglecting bias). This "bucking" voltage allows very little current to flow from either input lead to output common, effecting a large magnification of the intrinsic impedance to common. As in any potentiometric amplifier, practical loop gain values and other factors preclude infinite impedance; however, typical Dana Amplifiers exceed 350 megohms. The action of the CMA in simplified form is shown in Figure 6.4.

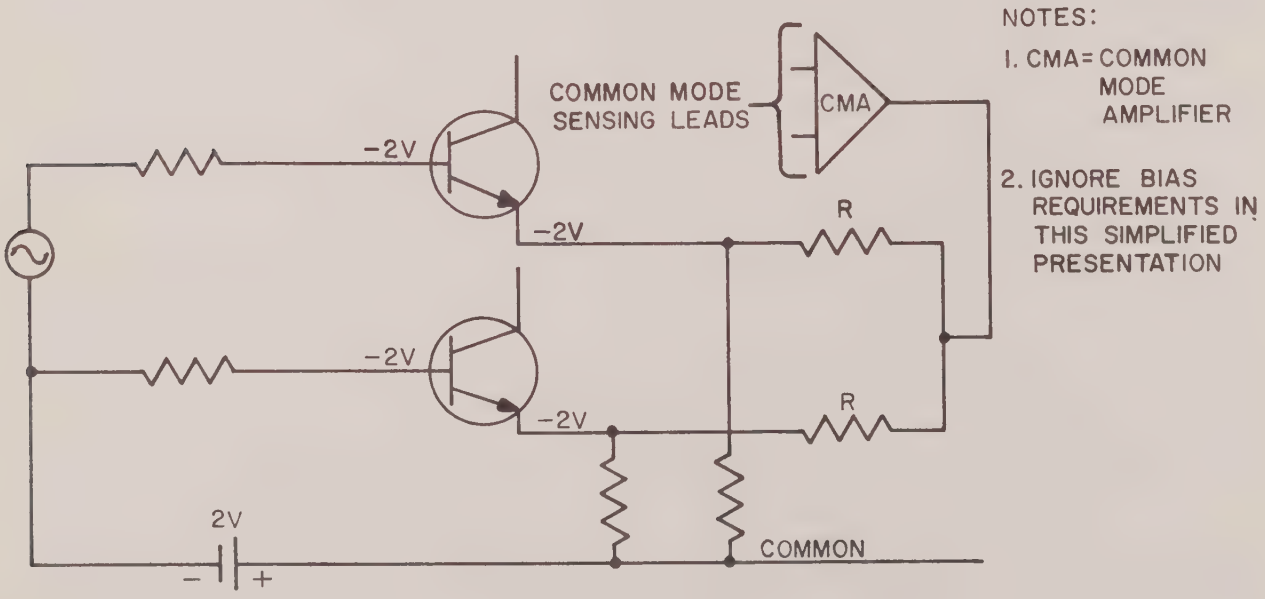


FIGURE 6.4 - Operation Of The Common Mode Amplifier

Reviewing the action of the Normal Mode Amplifier, differential input signals cause out-of-phase signals to be developed across the input pair's respective collector resistors. Under these conditions, the drop across the collector summing resistor (R1 in Figure 6.5) would remain constant; however, a voltage source

which is common to both input lines causes "in phase" collector current variations which add through R1 and produce a signal proportional to the Common Mode Potential, providing an input to the CMA. As illustrated in Figure 6.4, the CMA then couples a feedback signal to the emitters of the input pair (through R5 (s)) of the proper phase to cancel the effect of the input potential and maintain the sum of the two collector currents constant. As previously inferred, cancellation is complete except for a small residual error voltage necessary to maintain the output of the CMA very near to the Common Mode Potential (ignoring attenuator insertion loss).

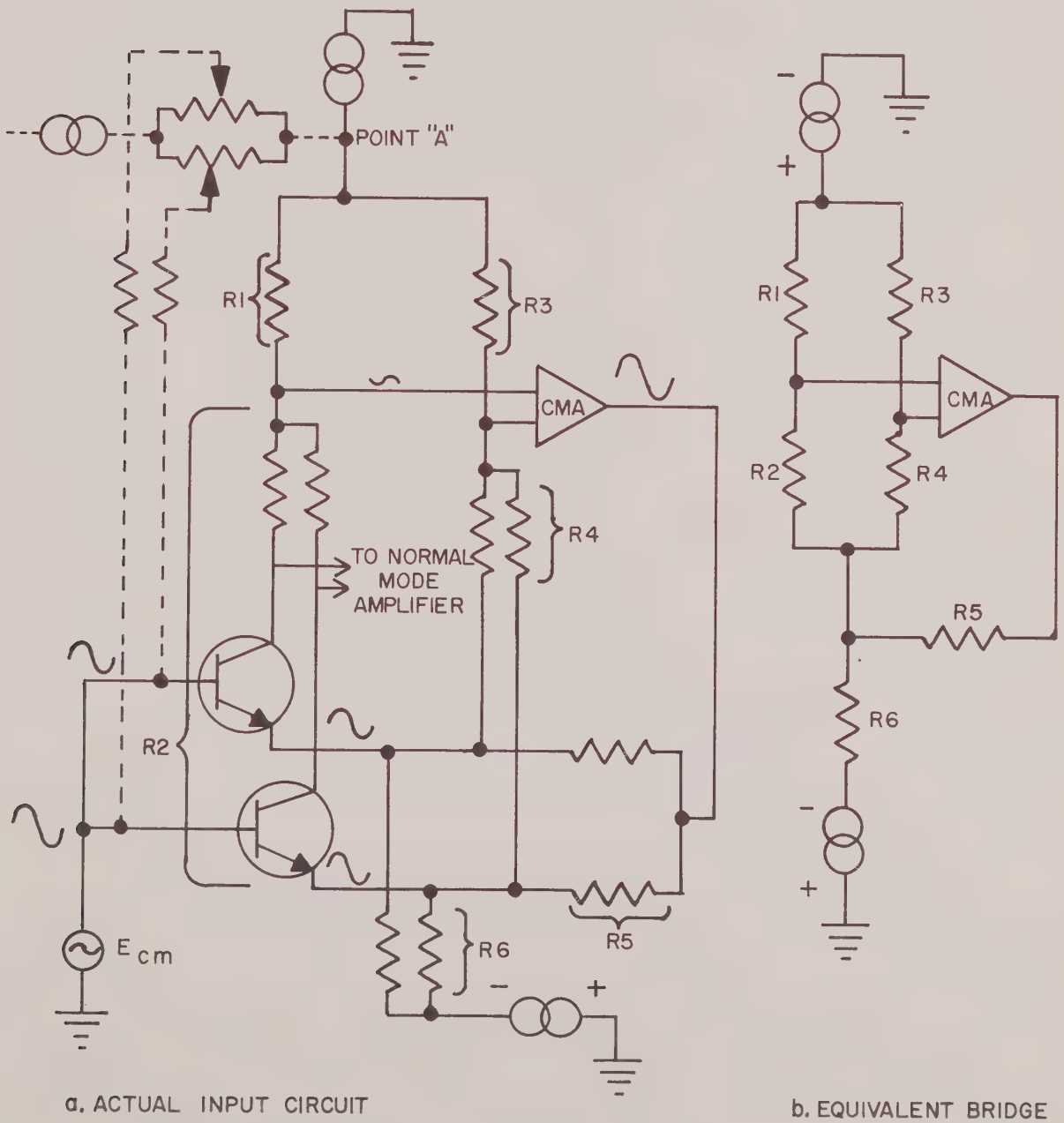


FIGURE 6.5 - The Common Mode Bridge

To facilitate the initial presentation of the CMA, it was described as though it might be a single-ended device referenced to ground; however, this is not the case. The CMA is a small differential amplifier much like the Normal Mode Amplifier and as such responds to the difference between its input terminals. In the actual circuit, one of the CMA input terminals is connected to the lower side of the input stage collector summing resistor and the other to a passive divider connected between the input pair emitters and the top of the collector summing resistor.

If this circuit is closely examined, it can be seen that the various circuit elements form a simple bridge. This identity is established in Figure 6.5b. In operation, the application of a common potential to the input transistors tends to unbalance the bridge by changing the conductance of the input pair. This effect is opposed by driving the lower end of the bridge (or the emitters of the input pair) with the output of the CMA. This feedback effectively cancels the change in conductance and restores the bridge to balance.

As previously stated, the parameters of the input stage are carefully adjusted for nearly identical characteristics and once established they cannot be allowed to change when the circuit is subjected to common mode potentials. Referring to Figure 6.5, it can be seen that the entire input circuit is floating between two constant current generators; and since it has been established that the active elements in the bridge circuit (transistors) are continuously balanced against passive elements (R1, R3, R4), it becomes apparent that the constant current sources will also serve to maintain constant voltage conditions across the bridge (constant I x constant R = constant E). This means that as the bottom of the bridge is driven up and down asynchronously with common mode potentials, the voltage at the top of the bridge will vary with the same relative magnitude. This bootstrapping effect raises the intrinsic CMR of the input pair to the high values required for high accuracy systems.

Feedback

As stated earlier, the differential input of this amplifier requires a feedback network slightly more complex than the simple divider shown in Figure 6.3. To illustrate, consider the case where one input is connected to a positive signal and the other to a negative signal. It would appear that the proper bipolar feedback for both inputs could not be derived from a single output terminal; however, this is not the case.

Figure 6.6 is the actual feedback network of the amplifier. For the purpose of the initial discussion, there will be no connection between points A and B, and it will be assumed that the amplifier has somehow arrived at the proper 10 Volt output for a 10 millivolt input (gain of X 1000). It can be seen that the voltage difference between the two feedback lines is the required 10 millivolts; however, both lines are approximately +5 volts above common. This is obviously intolerable and the circuit will not function until a connection is made between points

A and B. It should be emphasized that the +5 volts is common to both input transistors and would tend to unbalance the common mode bridge just as an external common mode potential would do. The only difference in the two situations is the fact that the "feedback" common mode voltage is internally generated and tends to drive the input emitters in lieu of the bases. The latter results in one less phase inversion for internally generated common mode signals, producing an output from the CMA of the opposite output would go negative until the feedback lines become approximately +5 millivolts and -5 millivolts with respect to common.

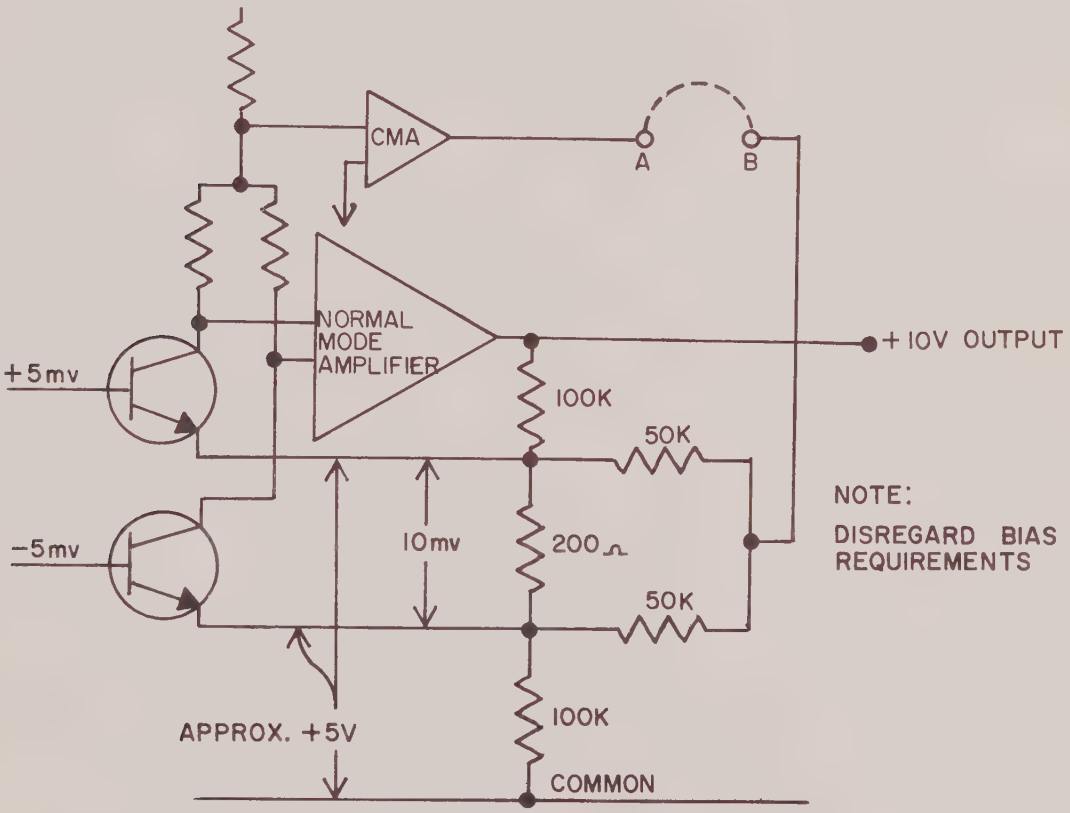


FIGURE 6.6 - Feedback Network for Gain of 1000

It can now be seen that the C.M.A. will not tolerate the bridge to be unbalanced at any time, whether the common mode potential is introduced internally or externally. More specifically, the collector currents are never permitted to shift in the same direction but can only vary by equal and opposite amounts in response to differential input signals. This fact holds true regardless of the symmetry of the input signals. To illustrate, consider the situation where one input is tied to common and the other is driven with a 10 mv AC signal. The C.M.A. will assume the proper signal level so that equal and opposite error

signals will exist between the base and emitter of each input transistor. The final quiescent conditions are shown in Figure 6.7.

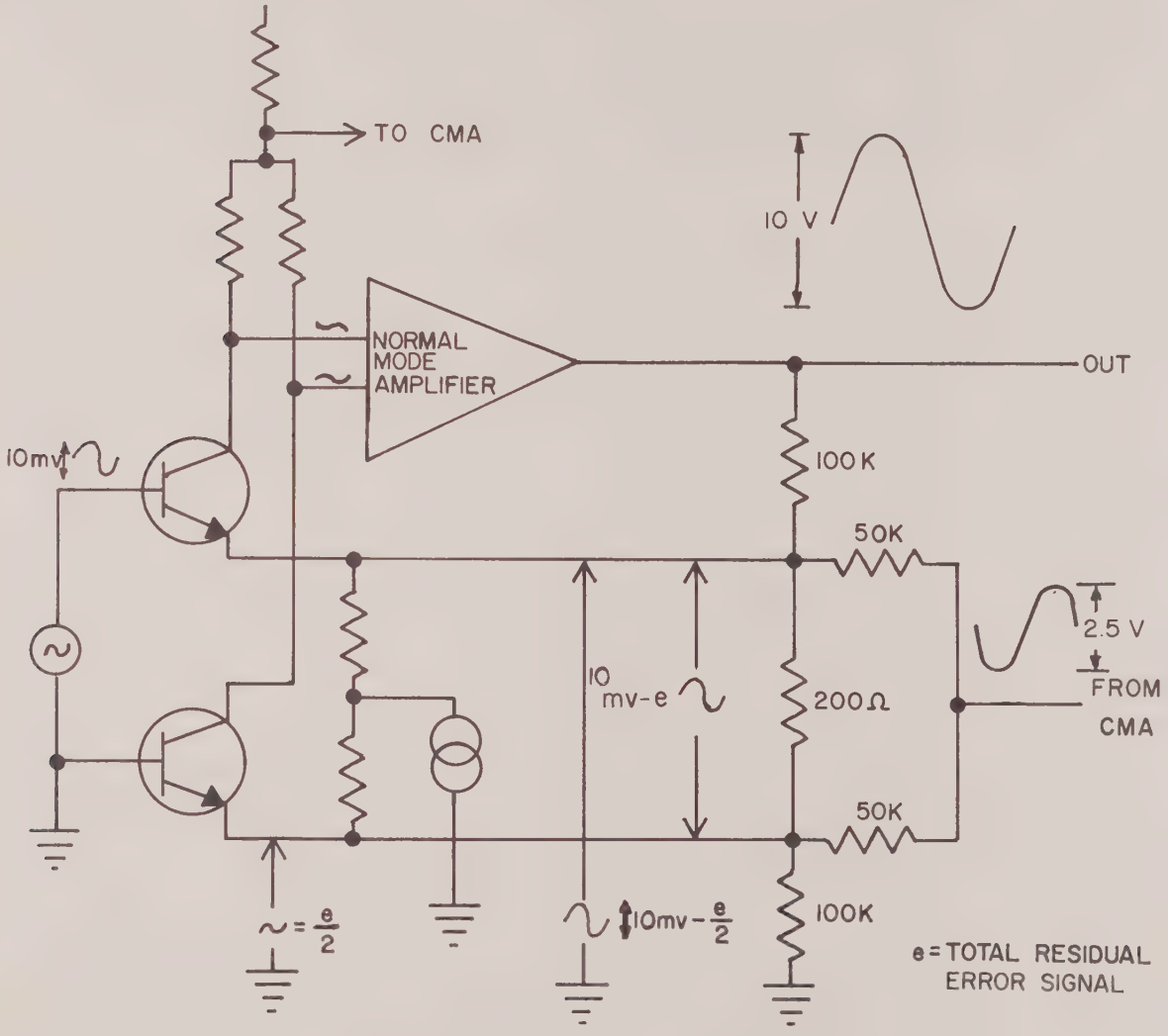


FIGURE 6.7 - Forced Internal Symmetry

Additional Circuit Details

To facilitate the initial presentation, a few circuit details were intentionally overlooked. Specifically, the diagrams used to illustrate certain fundamental points inferred a quiescent voltage level of zero at several points that are normally several volts positive or negative with respect to ground. Even so, the circuit action as described is fundamentally the same except that the signal levels are relative to the initial conditions.

The static bias condition of the input pair is of particular interest since it

is related to input current uncertainty. These stages are initially forward biased and though the base idling currents are quite low, they would develop an offset voltage if allowed to flow through the external signal source resistance. To minimize this effect, each input line is connected to a source that shunts this current to the amplifier's internal supplies. An adjustment is provided for each input line, permitting the input current to be periodically rezeroed in the field (shown in dotted lines of Figure 6.5). To prevent common mode loading, these sources are floated between a constant current generator and the top of the common mode bridge. Since both input leads and the collector supply move together with the common mode potential, the current through the base resistors remains very nearly constant. This infers that the impedance to common potentials is a large magnification of the apparent 5 megohms in each base lead (on the order of 1000 megohms); and also points out that the quiescent base current is virtually undisturbed by common mode potentials.

A second point which was not expressly brought out in the initial presentation is the relationship between the magnitude of the common mode potential and the voltage level at the output of the C.M.A. If the source of common mode is external, the output of the C.M.A. will be 50% greater than the applied voltage; if the source is internal (one-half of the output signal), the output of the C.M.A. will be $-E_{out}/4$. This relationship is solely determined by the ratio of the respective attenuator resistors.

6.5 OPTIONAL CIRCUITS

The Dana Amplifier is manufactured in modular form with the individual circuit boards dividing the amplifier by function; e.g., "Normal Mode Amplifier", "Common Mode Amplifier", etc. This approach permits a wide variety of combinations of complete amplifiers to be assembled in a building block fashion to meet the specific needs of the individual user. From an analytical point of view, this presents no problem since the fundamental theory of operation applies to all possible combinations. A description of the optional circuitry in general form is provided below. For specific details, refer to the specifications for the specific models; and the schematic diagrams in Section 9.

Gain Options	Several gain options are available that vary only in the number of fixed steps provided, the nature of the vernier, gain accuracy and resolution. These options do not alter the basic circuit characteristics but affect only the feedback network.
Output Options	A selection of two main output amplifiers is provided with current output capabilities of 10 or 100 milliamperes.

Bandwidth Options

Options are available with full unrestricted bandwidth, variable bandwidth, or both. The "Variband" units are identical to the basic amplifier except for the addition of a small, direct coupled output amplifier which is adapted as an active filter. The use of a separate amplifier permits the low impedance, filtered output to be available without increasing the complexity of the basic amplifier or affecting the normal wideband output. The cut-off frequency of the "variband" output is selected by a front panel control.

Isolated Dual Outputs

The preceeding options permitted a selection of two outputs with various combinations of output capability and bandwidth. These are referred to as having three wire outputs in that they share a common ground. In instances where complete isolation is required between the output common lines, one of the outputs is driven from a separate unity gain, differential amplifier with its own isolated power supply. This allows complete independence in terminating the two sets of output lines (within the Common Mode rating of the amplifier).

7. OPERATING CHARACTERISTICS & APPLICATION NOTES

Tabulated specifications provide a concise, quantitative means for relating an instrument to a potential application. It is also a means for comparing the relative suitabilities of competitive instruments for a given application.

However, an abbreviated description such as this must be used cautiously. Developments in the electronic industry are so rapid that terminology, test conditions, etc., are neither standardized nor binding. Consequently, different manufacturers and different users often apply the same term in different ways, or use different terms to describe the same quantity.

Dana Laboratories adheres to generally recognized standards when they are applicable. However, there are many test procedures and parameters that are neither standard nor well defined. The purpose of the following commentary is to convey to the user the exact meaning of the terms used by Dana in the design, manufacturing and testing of Data Amplifiers.

7.1 OUTPUT

In the case of the Dana Amplifier, output is defined as the voltage between the OUTPUT and COMMON terminals. Since both terminals are isolated from the amplifier chassis and power line ground, it is necessary to define the COMMON terminal as the reference point for all voltage measurements. This point is common both to the output and to the internal shielded power supplies.

For specified performance, the COMMON terminal of the amplifier should be connected to the low side of the load. Since many output devices have poorly shielded power supplies, it is often desirable to return this point to ground.

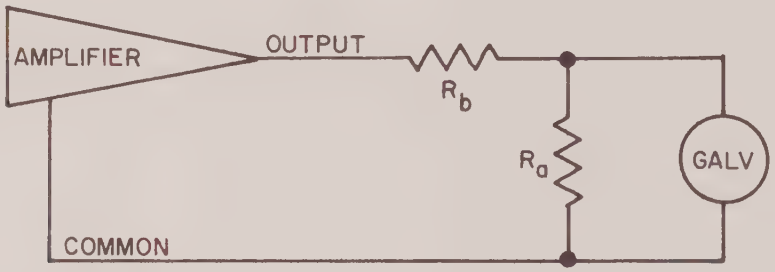
The full scale output of the amplifier is -10 volts to +10 volts dc, peak ac or any combination, at frequencies up to 20 kc with full rated load. Specifications such as gain accuracy, linearity, and output impedance apply to outputs within this full scale limit. At frequencies from dc to 20 kc, there is a nominal overscale capability of 20%. Lower output levels may be used beyond 20 kc.

The low current outputs will drive a load current of 10 ma peak. At 10 volts output, this corresponds to a load of 1000 ohms dc resistance or a 0.008 uf capacitance at 20 kc. If the load draws this current at a lower voltage, nearly normal operation will be maintained, but with some loss of gain accuracy.

A capacitive load of up to .05 uf for 10 ma units, and .5 uf for 100 ma units can be driven with no instability or effect on dc gain, linearity, or other

operating specifications. Under these conditions, however, the amplifier cannot be driven at full scale amplitude at frequencies above 8 kc due to dynamic saturation (see Section 7.9 - Slew Limiting).

If a low-resistance load, such as a recording galvonometer with a typical 25-ohm resistance, is to be driven, series resistance should be added so that the full scale of the recording instrument corresponds with amplifier full scale. This increases the accuracy of the instrumentation system and also serves to protect the recording instrument from damaging overload. Should the load require a particular driving resistance, such as an external damping resistance, a simple two-resistor network is needed between the amplifier and the load (see Figure 7.1).



VALUES FOR R_a AND R_b ARE DEFINED BY:

$$R_a = \frac{R_b R_d}{R_b - R_d}$$

AND

$$R_b = \frac{10\ V}{I_{FS}\left(1 + \frac{R_g}{R_d}\right)}$$

WHERE: R_d = REQUIRED EXTERNAL DAMPING RESISTANCE
R_g = GALVANOMETER RESISTANCE
I_{FS} = GALVANOMETER FULL SCALE CURRENT

FIGURE 7.1 - Two-Resistor Network For Damping Galvanometer

7.2 GAIN

Unless otherwise specified, the term "gain" means the ratio of the magnitude of $\triangle$Vo divided by the magnitude of $\triangle$Vi, where Vo is the output signal and Vi is the input. In the inverting mode, gain also means a change from minus full scale to plus full scale.

Linearity is so great that gain is essentially independent of Vo. Since the Dana unit is a negative feedback amplifier, the gain is determined almost entirely by the ratio of resistors in the feedback network. The specifications are valid for any gain from 20 to 1,000. A small degradation occurs in the 1,000 to 2,500 span. Considerable latitude exists in the number and value of gain steps that can be supplied between the limits of 20 and 2,500.

Gain Option V-1 provides a continuously variable gain from 20 to 2,500 in six ranges: 20-50, 50-100, 100-200, 200-500, 500-1000, 1000-2500, with a slight overlap between ranges. The resolution and mechanical stability of the continuously variable control limits the gain resolution of the amplifier to $\pm$0.1%. However, Option V-1 is particularly useful for applications where the load has a limited dynamic range, as in the case of magnetic tape recorders or recording oscillographs. In these applications, it is desirable to match the full scale of the transducer to that of the recorder. This requires either a very large number of closely spaced gain steps or a continuously adjustable gain. At the same time, the limited dynamic range makes it impossible to detect errors in the order of 0.1%. Because this vernier varies the feedback ratio in the amplifier, the frequency response is reduced at the clockwise (high gain) end of the span. Gain Stability is $\pm$.02% with the vernier at its low end.

Gain Option F-1 provides four fixed values of gain: 30, 100, 300 and 1000, with a vernier to adjust the fixed values $\pm$ 2%. Gain resolution and stability $\pm$0.01%.

Gain Options V-2 and F-2 are identical to V-1 and F-1 respectively except that a 100:1 input divider may be selected by a front panel control. This control is concentric to the main gain selector and has two positions with the legends X1 and X0.01.

7.3 GAIN MEASUREMENT

Because the amplifier can be operated as a noninverting, single-ended amplifier, very accurate gain measurements can be made using the test setup shown in Figure 7.2. The signal source need not be particularly accurate nor stable. It should be adjusted to produce a signal of approximately 10 volts.

However, the voltage divider must be extremely accurate, and the null detector must be isolated and resolve less than 1 mv. The divider is set so there is no change at the null detector when the polarity of Vi is reversed. When this is done, the gain may be calculated as follows:

$$K = \frac{1}{h}$$

where K = amplifier gain

h = ratio of voltage output to input of divider

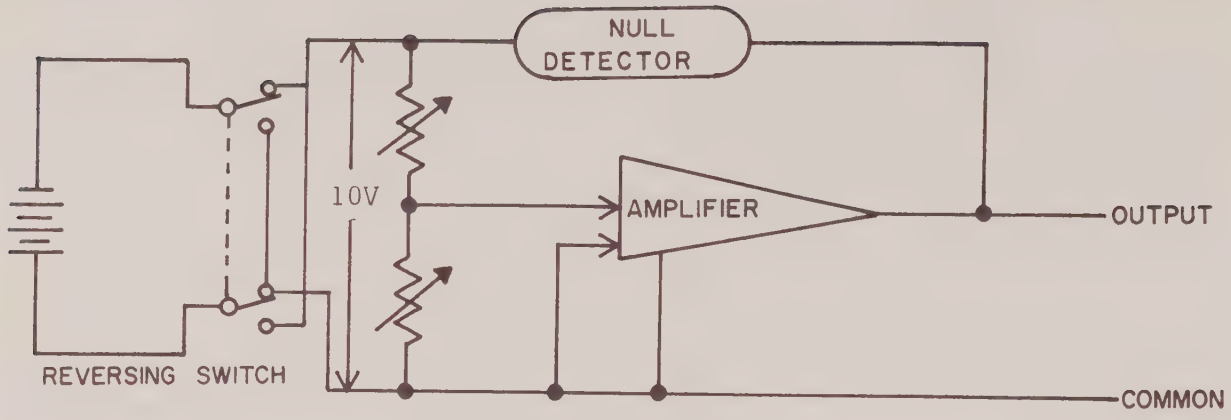


FIGURE 7.2 - Test Setup For DC Gain Measurement

7.4 AC GAIN MEASUREMENT

The gain-measurement technique described above can be extended to ac if the phase lag in the amplifier is compensated and a suitable null detector is used. If these types of measurements are anticipated, a special transformer and phase correction network may be procured from Dana; however, in general, a simpler and more direct method is recommended as described below.

A practical test setup for ac gain measurements is shown in Figure 7.3. A precision divider should be used that is of sufficiently low impedance to prevent errors due to source resistance. The output meter should be a good quality, average responding, AC voltmeter with a mirrored scale with at least 100 minor divisions. (H.P. 400H or equivalent).

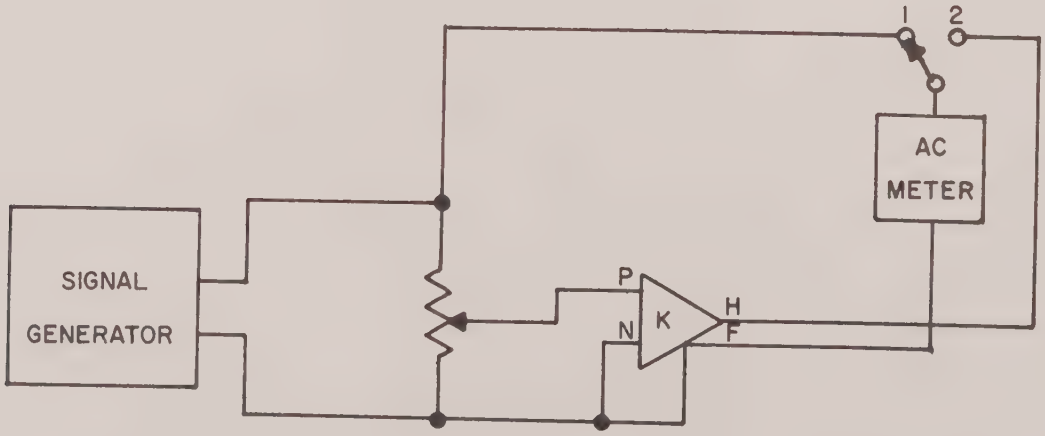


FIGURE 7.3 - Test Setup For AC Gain Measurement

After setting up the test equipment, the following procedures should be carried out.

1. Place the monitor switch to position #1 and set the signal generator to an output of approximately 7 volts RMS at 60 cps (other frequencies used for frequency response checks).

2. Select a minor division on the meters best scale (maximum resolution and legibility) and adjust the output of the signal generator very carefully to place the needle of the meter directly on this marker. Use the mirror to avoid parallax.

3. Set the monitor switch to position #2 and adjust the input divider for exactly the same reading established in step 2.

4. Carefully observing the meter, move the monitor switch alternately between positions 1 and 2 to insure that the reading is exactly the same in both positions.

5. Compute the gain of the amplifier by taking the reciprocal of the input division ratio.

7.5 LINEARITY

Ideally, gain should be independent of the magnitude of the output voltage from minus full scale to plus full scale. Since the Dana Amplifier's departure from this ideal is small, the null balance method of the gain measurement is again used. Linearity can be measured immediately after the DC gain measurement. (See Figure 7.2). The test setup shall remain the same except that a variable DC voltage is required.

Steps 1 and 2 are followed as before. The input voltage is then varied from minus full scale to plus full scale, and the peak reading of the null detector recorded. The linearity in percentage can be calculated as follows:

$$\frac{\text{peak null detector reading (volts)} \times 100}{\text{full scale (10 volts)}}$$

7.5.1 HIGH FREQUENCY LINEARITY

All amplifiers have inherent nonlinearities which are reduced by negative feedback. Since the feedback ratio decreases at higher frequencies, the nonlinearities become proportionally greater. In the Dana amplifier, AC linearity is better than .01% from DC through 2 kc as determined by the following equation:

$$\text{Linearity} \quad (\text{in \%}) \quad = 100 \left(\frac{|E_{out}| - K \ |E_{in}|}{|E_{out}| \ (\text{full scale})} \right)$$

To measure high frequency linearity, an extremely accurate AC/AC ratiometer is required such as the Dana Model 5640. The test setup is shown in Figure 7.4 and the measurement procedures are listed below.

1. Set the signal generator to approximately 7 volts RMS at 60 cps. Set the gain of the amplifier to X 1000.

2. Trim the input divider and/or the amplifier vernier control until the absolute ratio is .99990 (displayed on ratiometer as 9.9990). This reading indicates a slight gain error, however, this is not important to the linearity measurement and allows the latter to be made with greater resolution.

3. Leaving all other adjustments set, increase the frequency to 2 kc and observe the new reading on the ratiometer.

4. Linearity is computed as follows:

$$\text{Linearity in \%} = \frac{\text{Reading \#1 - Reading \#2}}{1000}$$

5. If no range changes are involved, the result can be more quickly computed by allowing .001% for each digit of difference.

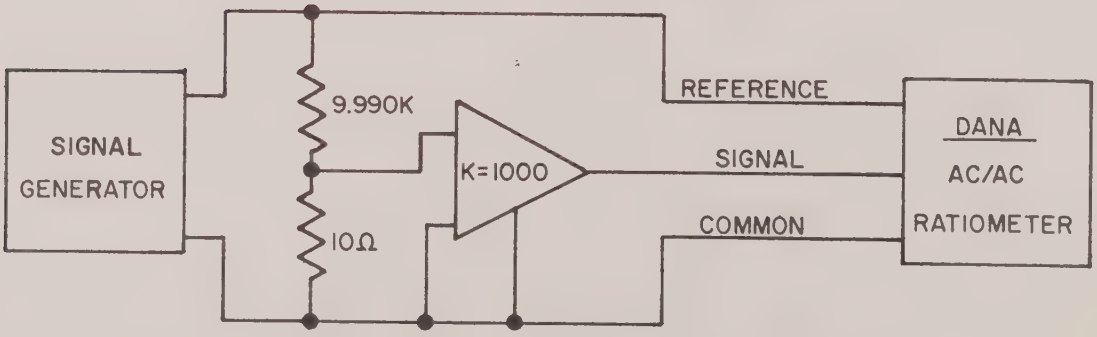


FIGURE 7.4 - Test Setup To Measure High Frequency Linearity

7.5.2 SLEWING SYMMETRY

It is commonly understood that nonlinear distortion will generate harmonics, second, third, fourth, etc. of the driving frequency. It is less commonly realized that a dc offset is also produced by nonlinear distortion. The Dana Amplifier will be offset by less than 0.01% of full scale when driven up to 20V P to P output, at any frequency from DC to 2 kc. This offset will increase with frequency, but in a simple controlled manner to at least 20,000 cps.

This can be encountered as a practical problem when the amplifier must be used wideband to drive a magnetic tape recorder or other wideband load, and the amplifier output is also filtered and measured digitally as in the case of dual output amplifiers.

At large amplitudes and frequencies beyond 20 kc a form of saturation may occur which is called slew limiting (see Section 7.9). Whenever this or any other saturation occurs, the offset is large and uncontrolled. The usefulness of data taken under these conditions is extremely questionable. If slew limiting is encountered, prefiltering is mandatory.

7.6 NOISE

Noise in a data amplifier is a complex function of bandwidth, gain, loop gain and other factors. The stabilization of large values of loop gain always produces a high degree of noise compared with open or low loop-gain amplifiers, such as radar amplifiers. Excess noise is unavoidable, particularly in the higher frequencies near the limit of the bandwidth.

In addition to the inevitable random noise, there may be systemic noise at the line or chopper frequencies of their harmonics. In the Dana Amplifier, systemic noise is so nearly nonexistent as to be undetectable in the total noise except by very sensitive narrow-band analyzers. Overall noise is random, but not uniformly weighted with respect to frequency.

Noise specifications are based on the total noise from an arbitrarily low frequency (10-20 cps) to the limit given. If less than the full amplifier bandwidth is specified, a single-pole, low-pass filter is assumed between the amplifier output and the noise-measuring instrument. The noise bandwidth is based on <u>power</u> transmission, not voltage. The noise power bandwidth, in cycles per second, of a single-pole filter is (1/4 T) not (1/2 T) (conventional -3 db point), where T = RC or L/R.

A true rms measurement is desirable, but the freedom from systemic noise makes reasonably accurate measurements possible with either an rms-calibrated average voltmeter or an oscilloscope (rms is approximately 1/6 the peak-to-peak value observed on the oscilloscope).

Noise on 1 kc bandwidth is typically 1 uv rms. On wideband, peak noise is under 3 x rms spec 98% of the time.

7.7 CHOPPER INTERMODULATION

At signal frequencies harmonically related to the chopper in a chopper-stabilized amplifier, beat notes are produced. For example, at an (2 fc $\pm$ x) input, an x frequency output is produced by a "chopper intermodulation". The Dana Amplifier does not exhibit this phenomenon and thus does not require this type of specification.

7.8 BANDWIDTH

Bandwidth is one measure of an amplifier's ability to respond to rapidly changing signals. There are other measures, including rise time and settling time. Each measure has its application and is not interchangeable with the others.

Bandwidth in the Dana Amplifier is defined as the maximum frequency at which the gain remains within a specified tolerance from the dc gain. For example, from dc to 20 kc the amplifier will stay within $\pm$ 1 db (within 89 to 112% of dc gain). At low amplitudes, the Dana Amplifier is flat to $\pm$ 3 db to approximately 50 kc on fixed gain steps, or at the low end of the adjustable gain settings.

The above refers to the basic non-restricted bandwidth of the amplifier. The bandwidth of "variband" units is -6 db at the cutoff frequency $\pm$ 1 db, decreasing at 12 db/ octave at higher frequencies.

Bandwidth may be determined by observing the <u>difference</u> in AC gain at low and high frequencies. This may be accomplished using the test setup shown in Figure 7.3. Since there is seldom a need to define bandwidth with extreme accuracy, the measurement procedures may be shortened as follows:

1. Follow steps 1, 2 and 3 with the signal generator set to 60 cps.

2. Increase the frequency to 20 kc and record the difference in readings between positions #1 and #2. If the meter has 100 minor divisions, each division represents approximately 1.4% of full scale.

3. In making the above measurement, it must be remembered that the bandwidth specifications apply for source impedances up to 350 ohms. When checking bandwidth make certain this value is not exceeded. If a low impedance divider is not available it may be necessary to improvise one.

7.9 SLEW LIMITING

All dc amplifiers, including the Dana unit, have a form of dynamic saturation called "slew limiting". The effect is to put a maximum limit on the rate-of-change of the output voltage, or dV/dt, and this in turn limits the peak voltage at a given frequency.

In certain cases, slew limiting may be due to an output current limit and a capacitive load so that: $dV_o/dt = I/C$. For example, if I = 10 ma and C = 0.02 uf, then dV_o/dt maximum = 500,000 volts/sec or a peak voltage of 4 volts at 20 kc.

It should be noted that slew limiting may be the result of factors both internal and external to an amplifier. With no load, the slewing rate of the Dana Amplifier is approximately 10^6 volts/sec.

7.10 STEP-FUNCTION SETTLING TIME

Rise time specifications are of only limited use in digital systems since rise time indicates only when the signal passes within 10% of its final value for the first time. In digital work, a much longer period, defined as settling time, must be used. Settling time is measured to a small residual error, such as 0.1%.

7.11 OVERLOAD RECOVERY

From a 500% input overload of any duration, the Dana Amplifier recovers to final value $\pm$.1% of full scale within 2 milliseconds. With an input overload of 10 volts, recovery to final value, $\pm$.1% of full scale, $\pm$ 10 uv referred to input occurs within 10 milliseconds. No damage will be sustained from input overloads of 30 volts DC or peak AC.

7.12 COMMON MODE REJECTION

At DC and very low frequencies, amplifiers of any type basically respond to the electrical "difference" between two points and do not respond to potentials between these two points and a third point, such as a specific earth ground (common mode potential). The fact that two types of amplifiers can yield two different results when connected alternately to a given pair of signal lines can only be attributed to the fact that once connected, the new current paths introduced by the amplifier cause new and undesirable "difference" voltages to be developed which constitute an actual input signal. These new "difference" potentials are the result of unsymmetrical IR drops in the input circuits, caused by potentials common to both input lines. If the impedances involved are perfectly symmetrical, the sum of the IR drops will equal zero and no difference signal will be seen. Similarly, if the common potential is

open circuited, no current can flow and no difference signal will be developed. Since it is seldom practical to balance the complete input system (including the amplifier) the only alternative is to raise the effective common mode impedance of the circuit, reducing undesirable currents to a minimum. For this reason, simple Common Mode Rejection specifications are meaningless unless fully defined in terms of impedance.

Figure 7.5 shows a balanced differential amplifier specified to have a common mode rejection of 100 db. Operating in a practical circuit with 100 ohms of resistive unbalance and a common mode potential of 1 volt, it can be readily seen that the actual rejection is far less than 100 db.

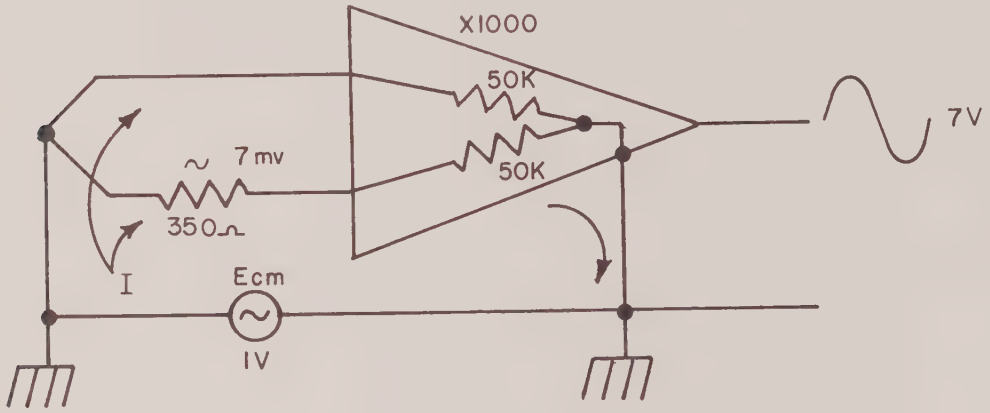


FIGURE 7.5 - Common Mode To Normal Mode Conversion

In addition to illustrating the importance of common mode impedances insofar as the amplifier is concerned, the diagram in Figure 7.5 can be altered to show that the same degradation can occur without an amplifier. To illustrate, mentally reposition the 50K resistors outside of the amplifier to represent the cable capacity of an improperly driven cable (approximately 500 ft. of 100uuf/ft. at 60 cps). Under these circumstances, the amplifier cannot possibly break the circulating currents and even with a perfect amplifier the system common mode rejection would be only 43 db.

The Dana Amplifier is similar to the unit shown in Figure 7.5 in that the input is nearly symmetrical; however, the effective impedance seen by each input line is greater than 350 megohms at DC through 60 cps. With this high impedance, common mode rejection is 120 db with up to 350 ohms of input unbalance.

7.13 SYSTEM COMMON MODE REJECTION

As previously noted, improper system connections can allow common mode currents to flow through source impedances and develop undesirable "difference"

potentials that appear as normal mode signals to the amplifier. A typical example of improper cable management is shown in Figure 7.6. In this diagram, the common mode voltage sees a complete circuit through the source resistor and cable capacity to ground at the amplifier site. Note that the amplifier's effective impedance to ground is in parallel with the cable capacity. This again illustrates that even with infinite isolation, the amplifier cannot control external current paths and considerable care must be exercised in designing the system or the fine isolation of the amplifier will be wasted. To further illustrate the importance of great care, it might be noted that one inch of cable (100 pf/foot) is approximately 350 megohms at 60 cps. Equal to the CM impedance of the amplifier!

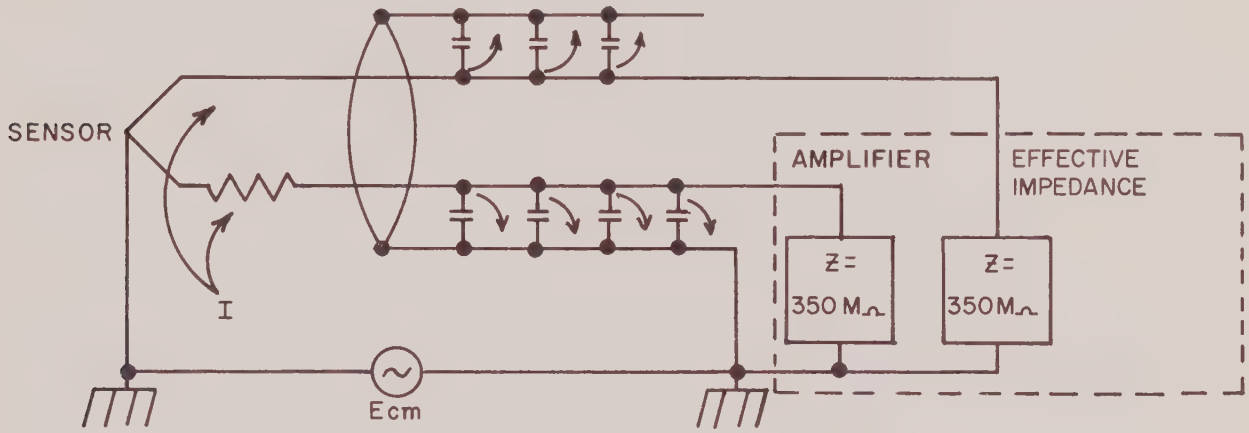


FIGURE 7.6 - Improper Shield Connections

Figure 7.7 shows a properly guarded system with the shield being driven at the common mode voltage. This almost eliminates the effective capacity between the signal lines and the measurement site ground, sharply reducing common mode currents through the source resistance. Currents that do flow, will pass harmlessly through the guard shield. Unfortunately, it is normally impossible to drive the guard at the precise Common Mode Voltage, therefore, the cable capacity cannot be completely neutralized. Furthermore, pin holes in the cable, together with exposed wiring in patch panels, terminal strips, etc., typically combine to produce an effective impedance between each input line and ground of less than 10 megohms at 60 cps. Since shunting this impedance with the 350 megohms of the Dana Amplifier would obviously produce very little change, it becomes quite clear that the total CMR of the system is essentially determined by the system itself...not the amplifier. Practically speaking, a well designed system will have a maximum CMR of 90 to 100 db with typical source unbalances. This renders the CMR of the amplifier virtually academic above 110 or 120 db.

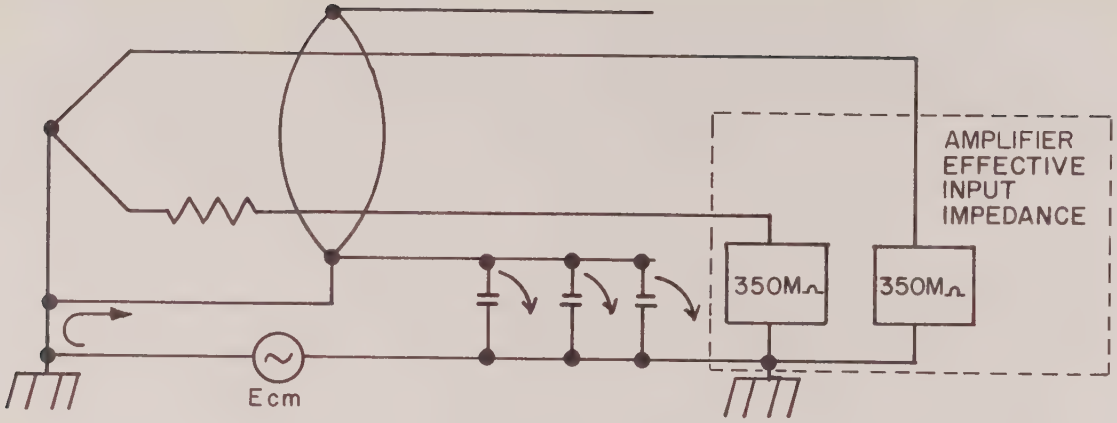


FIGURE 7.7 - Shunting Common Mode Currents By Guarding

Full comprehension of the above limitations introduces a second important consideration into the design of the system: control of the magnitude of the CM potential. To illustrate, consider a system with the following design objectives:

a) Full scale 0 to 10 millivolts
b) Accuracy .25% (exclusive of transducer and recorder)

Assuming that the system will have a CMR of 100 db (not a minor design objective) and that .1% of the accuracy tolerance can be alloted to common mode components in the output signal, the total error voltage (CM voltage converted to Difference voltage) at the amplifier's input terminals cannot exceed 10 microvolts. This limits the total common mode voltage to 1 volt ($\frac{1V}{10^5}$ = 10 uv). In the event a system CMR of 100 db cannot be realized, the maximum CMV is even lower.

Control of the CMV varies in complexity as a function of the local conditions. In many instances no specific action is necessary, or a simple bus wire may be required between sites. In other cases, efforts such as strapping structural members, balancing three-phase loads to neutral, line filters installed on interference generating devices, etc., must be pursued.

7.14 INPUT IMPEDANCE

The input impedance is essentially a stable, passive 10-megohm dc resistance. Capacity shunt effects are allowed for in the frequency response and source impedance specifications.

The amplifiers are designed especially to be operated from low-level transducers such as thermocouples and strain gages. The 10 megohms will cause a loading error of 0.0035% when operated from a 350-ohm strain gage. Even this

minute error is absorbed by normal strain gage calibration procedures. Thermocouples usually have even lower internal resistances. Operation from higher source impedances is possible with some degradation in performance characteristics.

7.15 ZERO DRIFT

Characteristically, zero drift is the greatest single error in data amplifiers. This drift has no effect on frequency response, linearity, and other parameters, but merely displaces the output. There are two components of drift; voltage and current. The voltage component of drift can be measured if the input is shorted, or if operation is from transducers of such low resistance as to make negligible the effect of current drift.

The Dana Amplifier drift specification, based on a fixed 0-350 ohm signal source, is $\pm$ 0.02% of full scale, or $\pm$ 2 mv referred to the output in 200 hours. This is $\pm$ 2 microvolts refined to the input when the gain is set to X 1000.

In addition, the temperature coefficient specification is $\pm$ 0.001% of full scale and $\pm$ 1 uv referred to the input, per-degree-centigrade temperature change. This totals $\pm$ 1.1 uv/per ^{o}C referred to the input at K = 1000. Since this also includes the source unbalance, both voltage and current errors are summed.

7.16 OFFSET CURRENT

A portion of the zero drift is due to an IR drop in the transducer. Resistance is normal to dc output type transducers, and all dc amplifiers produce some offset current through the transducer. In the Dana Amplifier, the offset current is typically less than 5 X 10^{-9} amperes from each input, returning through the transducer to common at 25^{o}C. This may change approximately $\pm$ 10^{-9} amperes per degree centigrade. The Dana Amplifier drift specification is based upon a maximum fixed source resistance of 350 ohms and includes the change in the IR drop. Higher resistance transducers may produce larger than specified drift/temperature coefficient because of this effect.

Dana Laboratories hopes that the above section has helped you to understand the nature of data amplifiers and will help you to put the Dana Amplifier to the most effective use in your application.

8. MAINTENANCE AND ADJUSTMENTS

Conventional instrumentation amplifiers are often difficult to troubleshoot, since the average malfunction causes abnormal readings or signal levels to appear throughout the loop. By comparison, the Dana Amplifier is far easier to service since the various direct coupled circuits can be readily isolated and inspected independently. In addition, the complete modular construction permits substitution. Printed circuit extender cards are available for those who wish to repair defective cards in the field, or find it impractical to maintain a set of exchange boards.

Before replacing a defective component, refer to the parts list. Certain components should not be replaced in the field without consulting the factory. These include, but are not limited to, the dual transistors in the normal mode amplifier and the selected precision resistors in the input stage. The latter can be replaced provided the replacement is an exact duplicate. If the resistance value is not legible, consult the factory referencing the amplifier's serial number and the circuit symbol number.

Adjustments

At periodic intervals, certain performance characteristics should be checked and internal adjustments made as required (see Section 7). The proper procedure for making these adjustments should be followed carefully.

Collector Zero Set

In addition to the operational zero control on the front panel, the amplifiers are equipped with an internal zero adjustment accessible through a small hole at the top of the Normal Mode Amplifier. (See R-14, NMA Component Location Guide, Page 9.2). Procedures for proper adjustment of this control are set forth below.

1. Connect amplifier inputs N and P to output common F.
2. Connect a millivolt meter to the output (Hewlett Packard 412A or equal).
3. Energize the amplifier and allow it to reach thermal stability.
4. Set the amplifier gain control to the lowest range and adjust the external zero control R-1 for minimum reading on the millivolt meter. (Front panel accessible, see Page 9.1). Record any residual offset.
5. Set the amplifier gain control to the highest gain position and adjust the internal collector zero control for the same offset recorded in step 4.
6. Repeat steps 4 and 5 until the output remains the same on both gain ranges.

Input Current Adjustments

The amplifiers have two adjustments that are used to minimize current flow through the input terminals. These adjustments are made as follows:

1. Set the amplifier to its maximum gain position.
2. Connect a millivoltmeter or oscilloscope to the output terminals.
3. Connect input terminals N and P to output common F.
4. Record any slight offset observed on the scope or meter.
5. Disconnect the "N" input terminal from output common and reconnect with a 1000 ohm resistor in series.
6. Adjust the "N" current control for the same offset recorded in step 4. (See R-17, Normal Mode Amplifier, Component Location Guide, Page 9.2). Repeat steps 3, 4, 5 and 6.
7. Remove the 1000 ohm resistor from the N lead and place in series with the "P" input, returning "N" to output common. Adjust the "P" current control (See R-18, NMA, Component Location Guide, Page 9.2) for the same offset recorded in step 4. Repeat steps 3, 4 and 7. (This adjustment not required on Model 2200-S-242.)

Common Mode Adjustments

The amplifier has two controls that affect common mode rejection by adjusting the symmetry of the input circuit. R-24 compensates for resistive unbalance and C-08 adjusts the capacitive symmetry. The physical location of C-08 is shown on page 9.2. R-24 may be located by referring to the appropriate Attenuator Component Location Guide (Page 9.6, 9.8, 9.10, 9.12 or special manual addendums). Once adjusted, these controls seldom require attention unless printed circuit boards are interchanged or components affecting balance are replaced.

When adjustment is necessary, an extender card should be used to gain access to C-08. Otherwise, a system of trial and error must be employed. The adjustment procedures are shown below.

1. Connect both inputs (N and P) to the high side of a signal generator, returning the low side to output common F.
2. Connect the signal generator to the X axis of an oscilloscope with the X axis sensitivity set to 5 volts/cm.

3. Connect the amplifier output to the Y axis of the oscilloscope throught a single pole, low pass filter consisting of a 16K resistor and a .01 microfarad capacitor.
4. Set the oscillator to 20 volts p to p at 60 cps and the amplifier to a gain of X 1000.
5. Adjust R-24 and C-08 for minimum vertical deflection.

Input Gain Symmetry

Those models which are equipped with X0.01 gain multipliers have a potentiometer (R-25 on the attenuator board) which is used to establish gain symmetry between the two input lines when the input attenuator is activated (X0.01 position). This adjustment serves two related purposes. Specifically it permits common mode rejection to be optimized when operated from balanced sources and at the same time equalizes single ended gain between inverting and non inverting connections. Maladjustment of this control in models permanently jumpered for single ended operation causes only a minor gain error when the X0.01 multiplier is selected. This control is adjusted as follows:

Standard Models

1. Set the amplifier gain switch to X 1000 and the input multiplier to X0.01.
2. Connect the N and P input terminals to the high side of a signal generator set to 60 cps and maximum output (not to exceed 250 volts peak). Return the low side of the signal generator to output common.
3. Connect an oscilloscope to the amplifiers output terminals and adjust R-25 for minimum deflection.

Special Single Ended Units

1. Set the gain multiplier to the X 1.0 position and the course gain to X 1000.
2. If the unit is equipped with a continuous gain vernier, (X1 to X2.5) adjust same for minimum gain. If the unit has a $\pm$ 2% gain trimmer it should not be adjusted.
3. Perform a routine gain accuracy check as descirbed in paragraph 7.3 and record the result.
4. Switch the gain multiplier to the X0.01 position, check gain accuracy, and record the result.
5. Adjust R-25 until the gain recorded in step 4 is equal to that recorded in step 3 divided by 100.

Output Current Limiters (100 ma wideband units only)

1. Connect the amplifier under test to a suitable 60 cps signal (preferably a signal generator and a voltage divider).
2. Connect the amplifier output to an oscilloscope with a 100 ohm load resistor shunted across its input terminals.
3. Adjust the signal source until the display is 25 volts p to p.
4. Adjust the positive and negative limit potentiometers , R17 and R11 respectively, to a position where the positive and negative peaks are just beginning to clip. These potentiometers may be physically located by referring to page 9.16.

Output Zero Adjustment

Dual output amplifiers have an additional zero control on the second output amplifier. This control is adjusted as follows:

1. Connect the input terminals N and P to output common terminals F and J. Connect this point to ground.
2. Connect a millivoltmeter or oscilloscope across the wideband output terminals and adjust the front panel zero control for minimum reading. Record any residual offset.
3. Connect the millivoltmeter to the variband output and adjust the output zero control for the same offset recorded in step 2.

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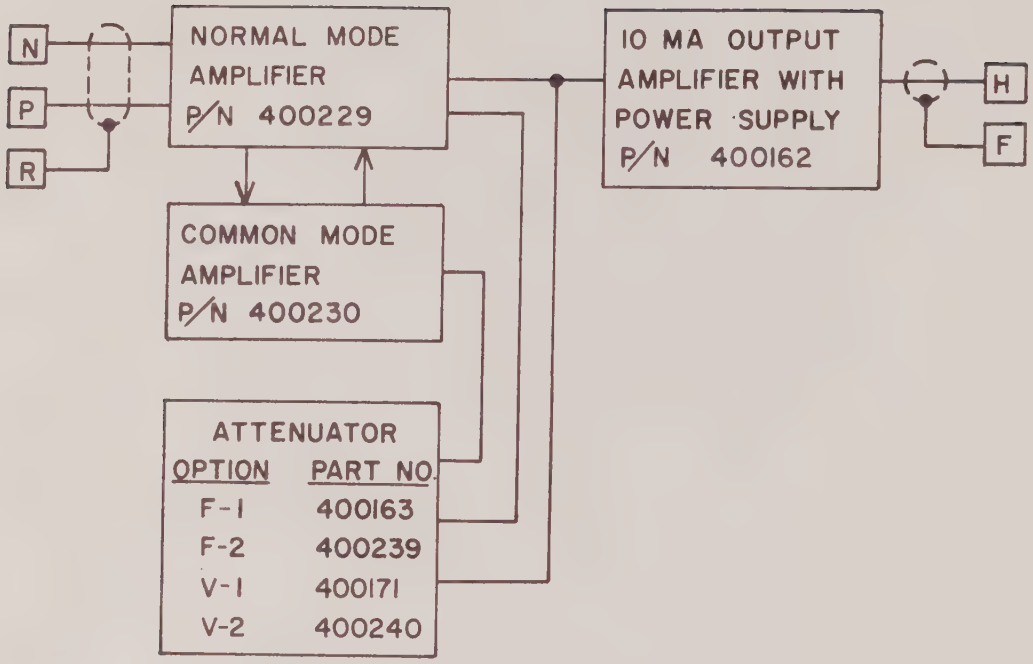
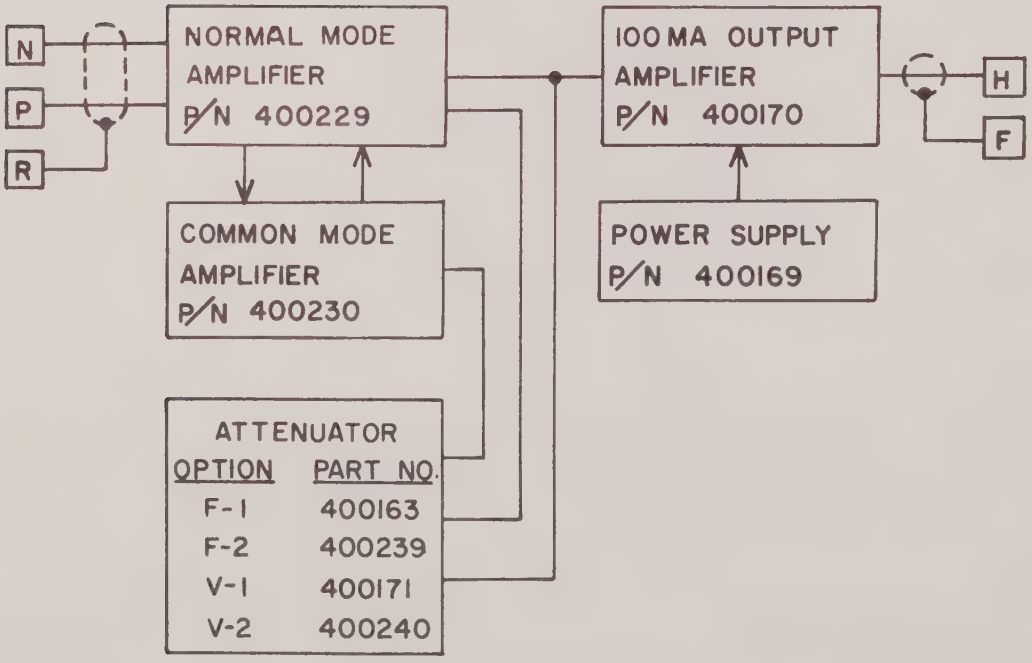
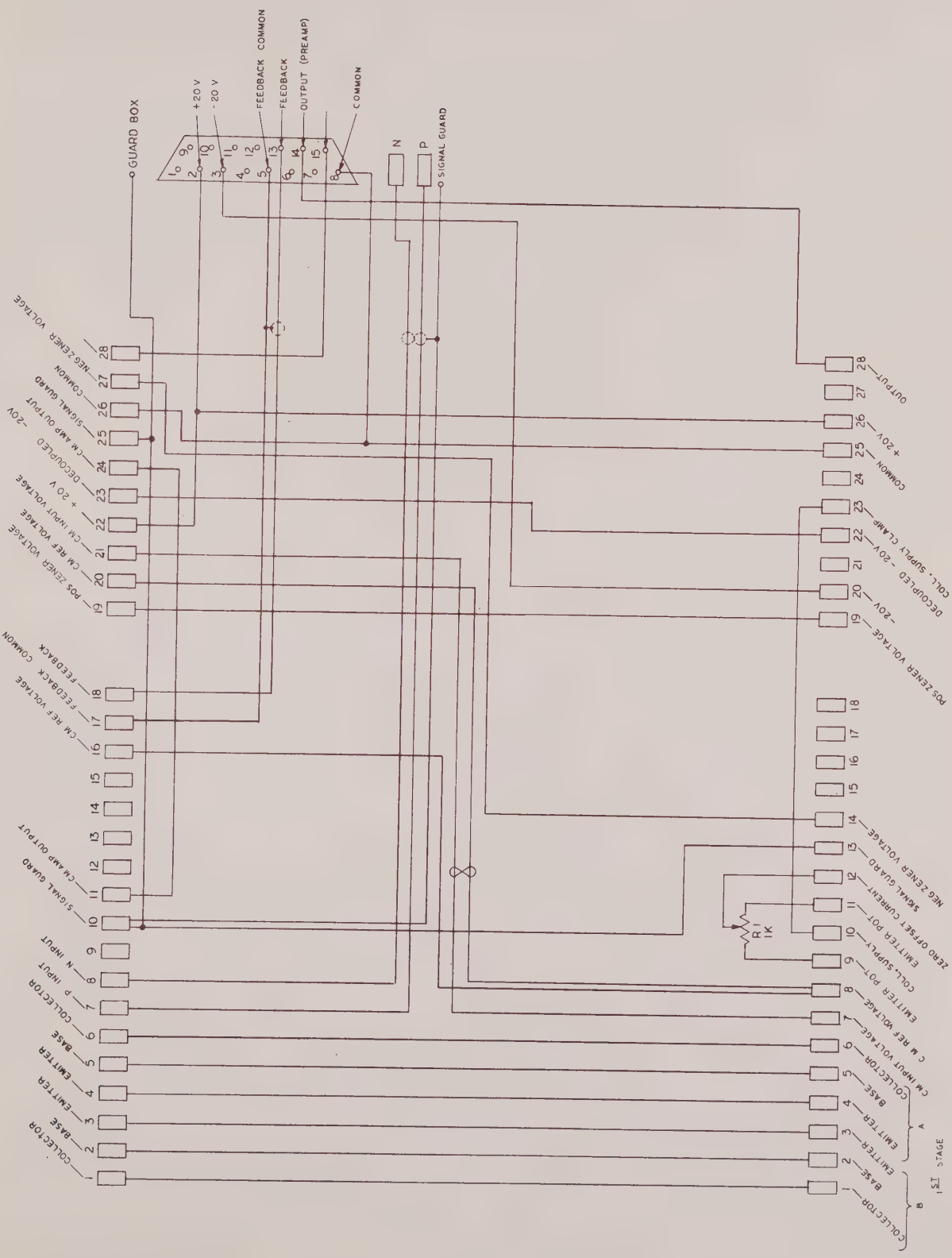
9.45	Miscellaneous Parts List



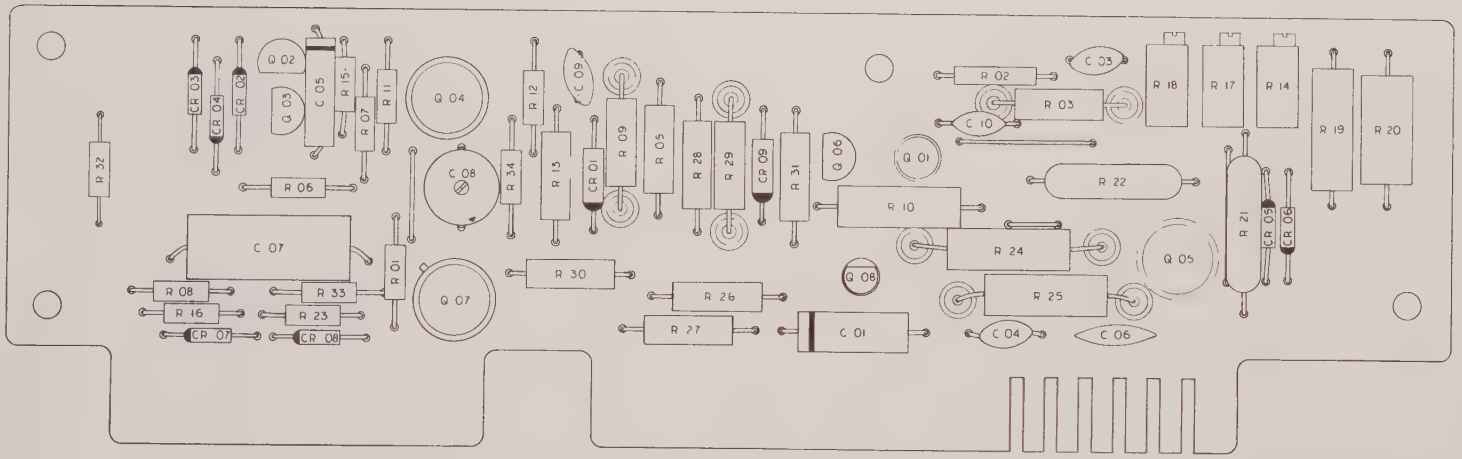
BLOCK DIAGRAM - MODEL 3400



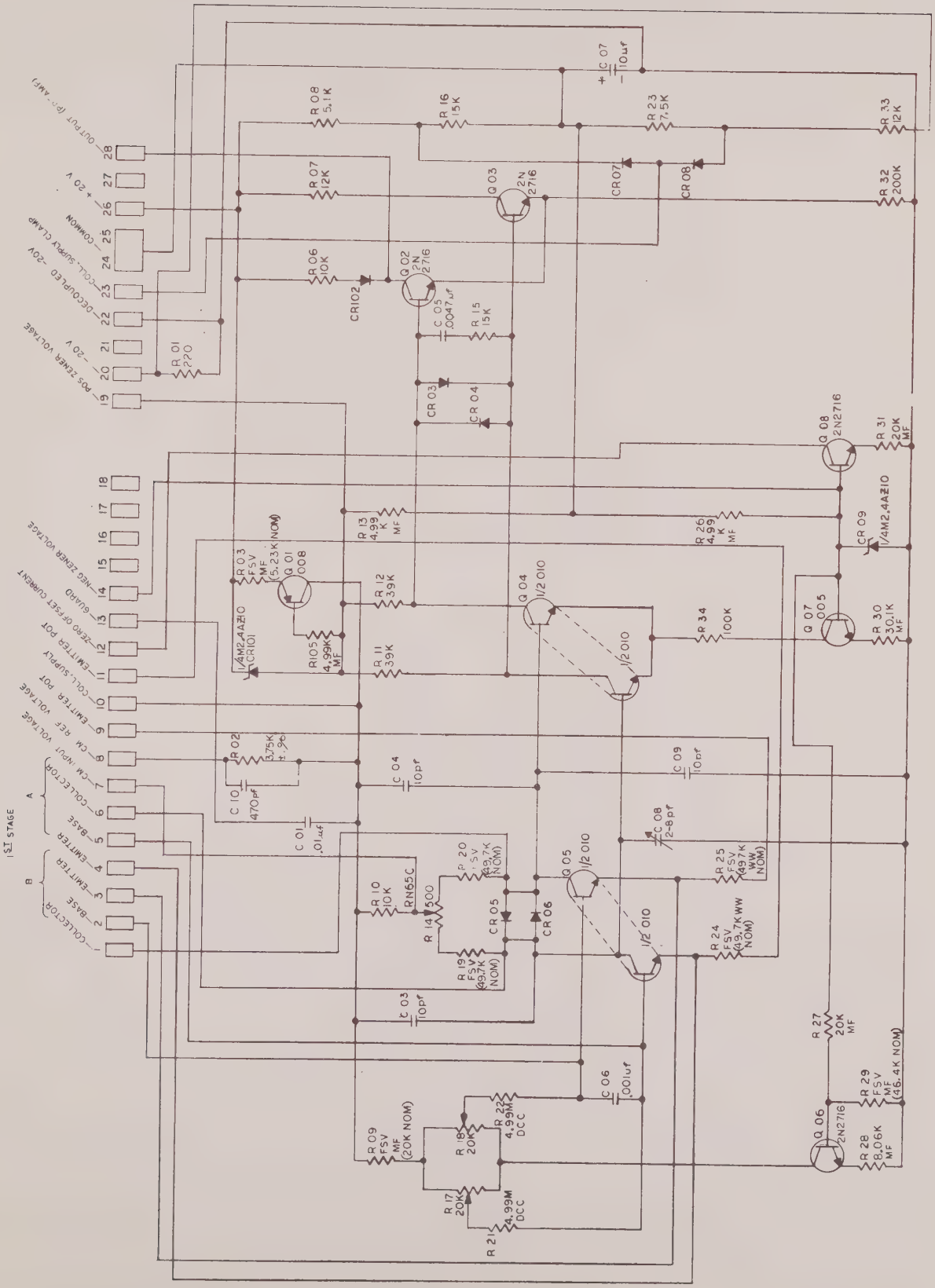
BLOCK DIAGRAM - MODEL 3420



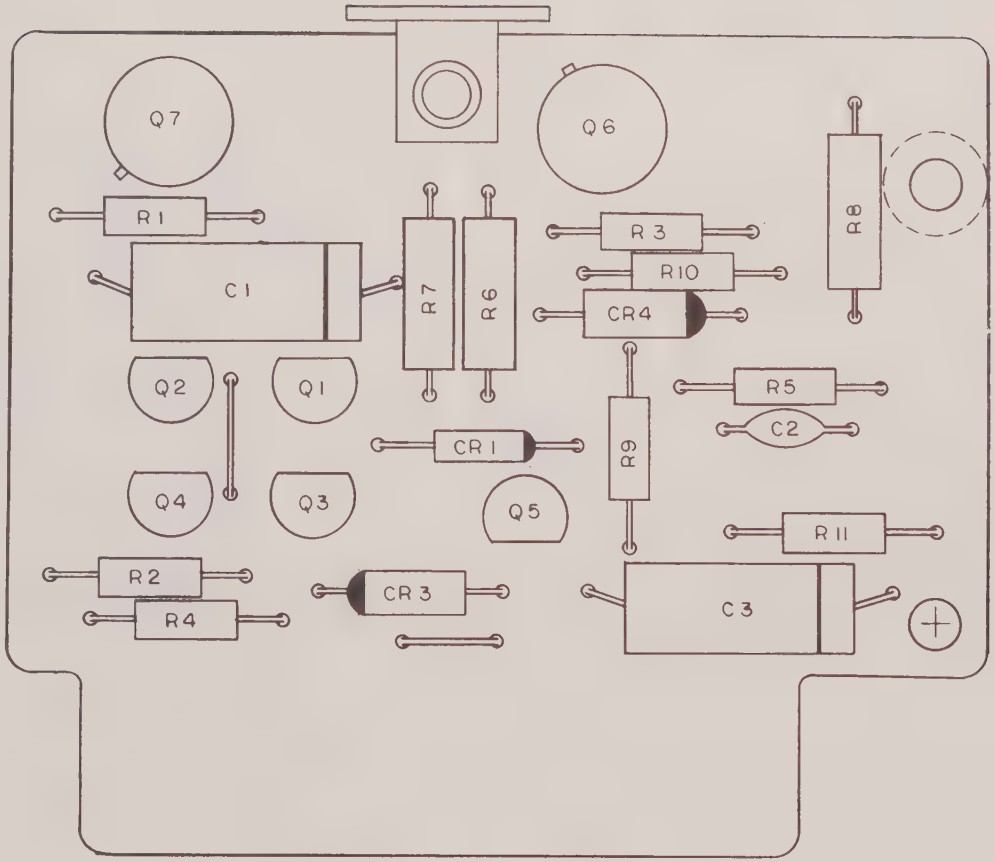
Cable Assembly Diagram



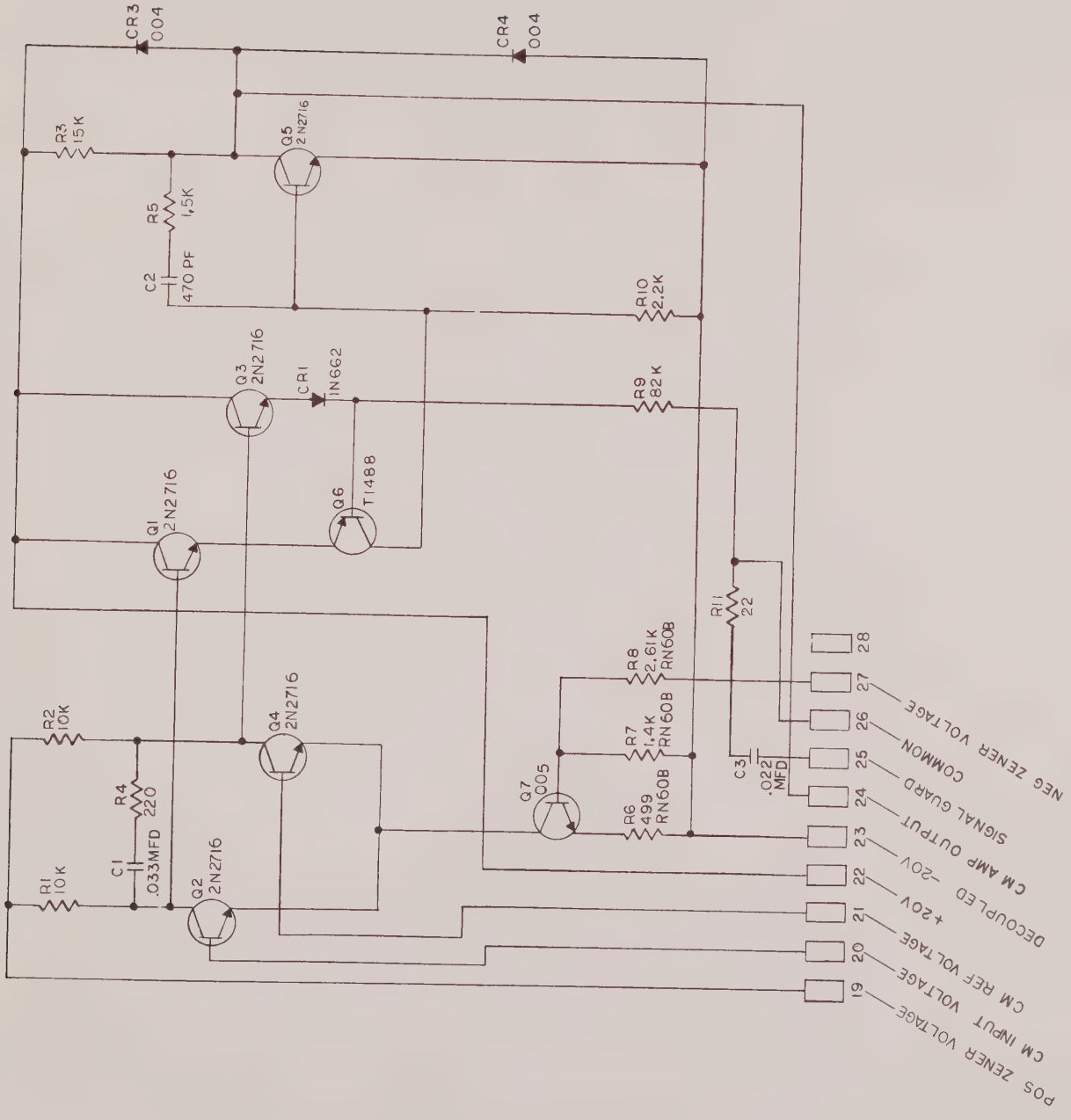
Normal Mode Amplifier - Component Location Guide



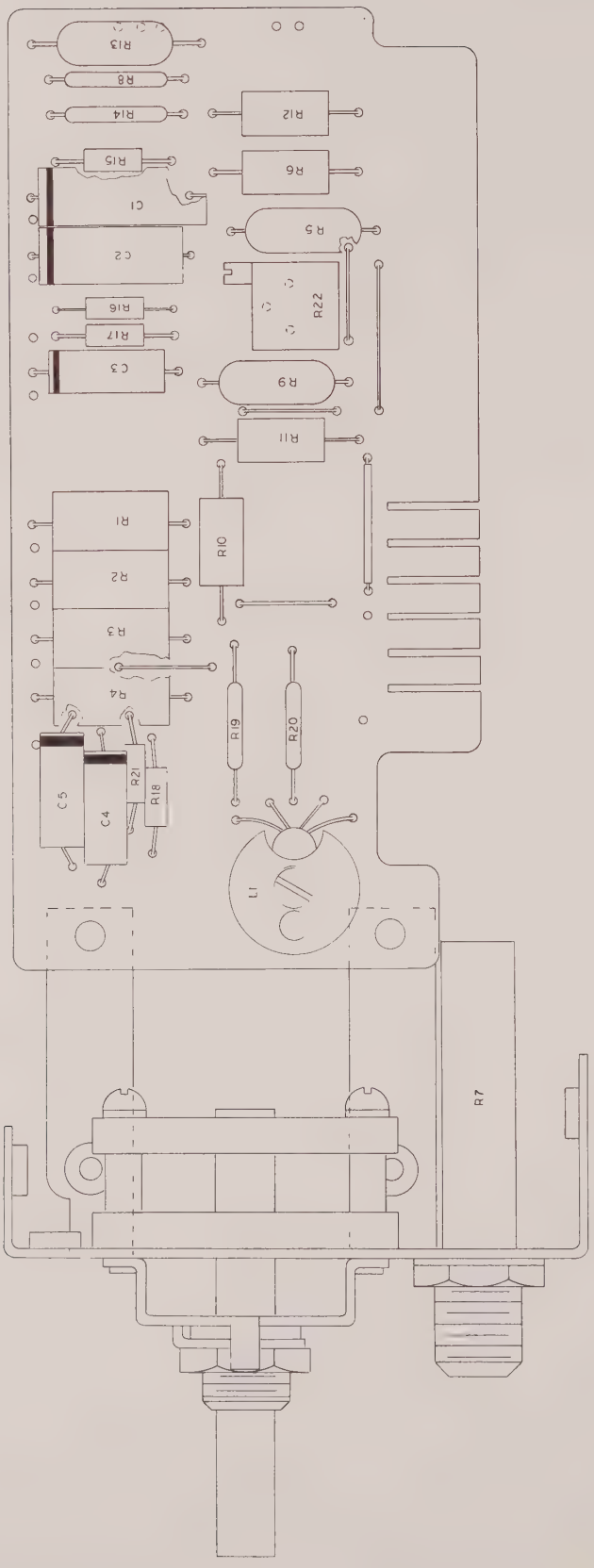
Normal Mode Amplifier Schematic



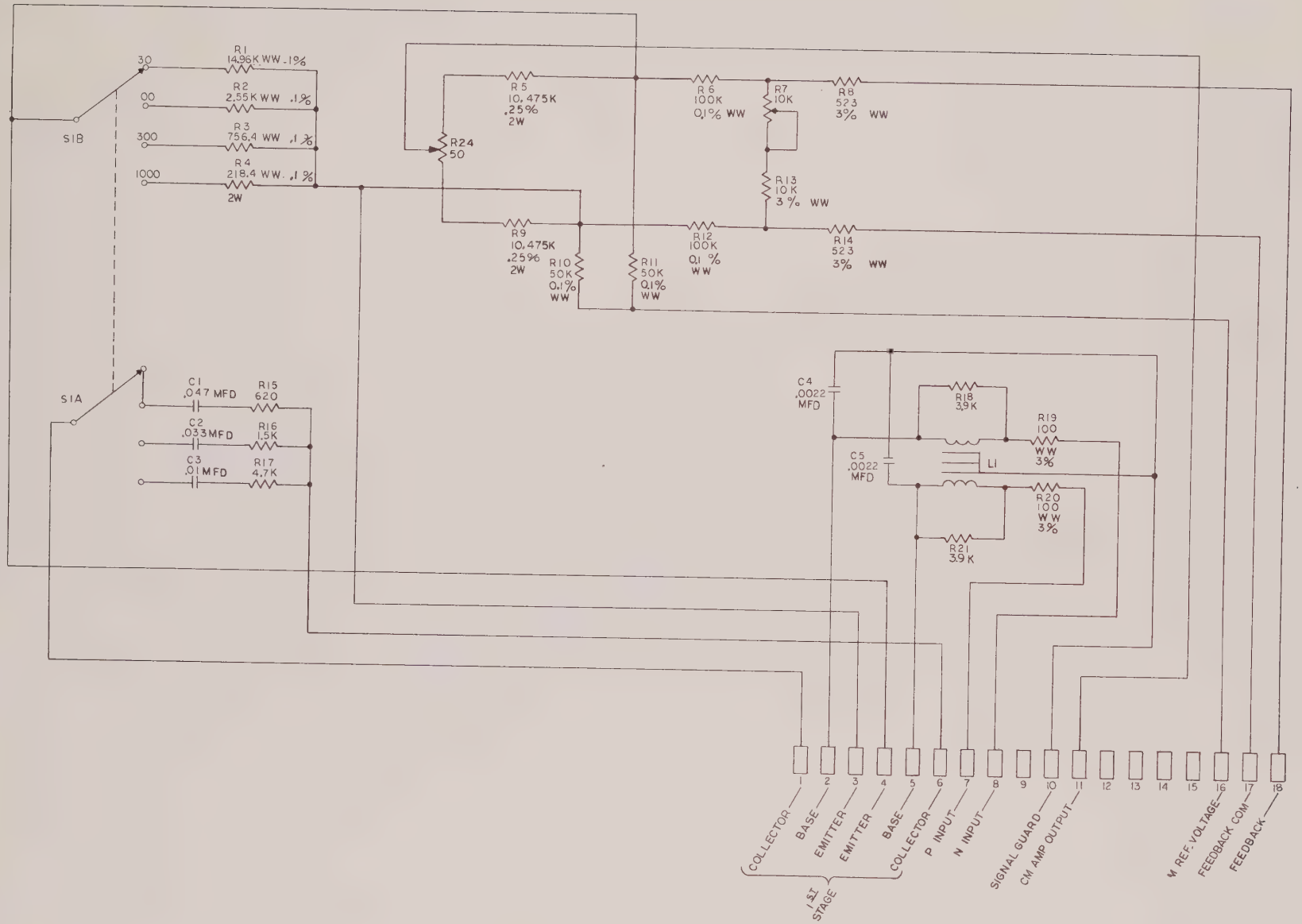
Common Mode Amplifier - Component Location Guide



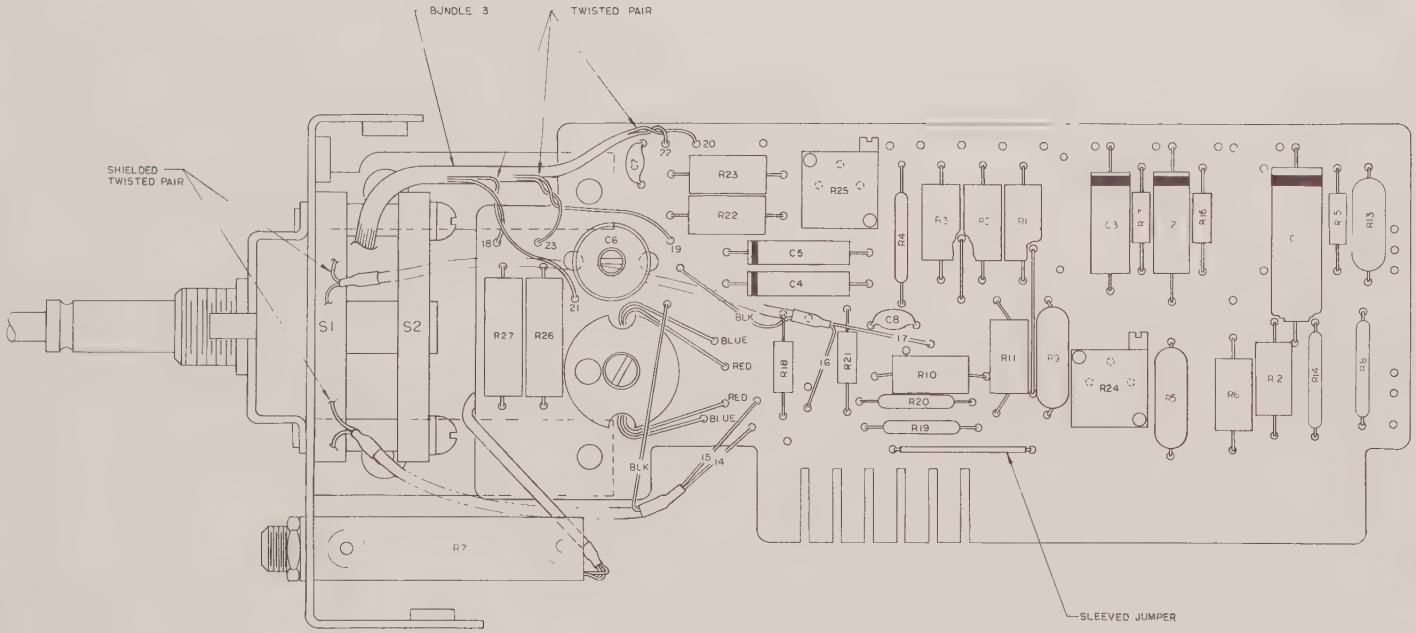
Common Mode Amplifier Schematic



Attenuator, Optiom F-1 - Component Location Guide

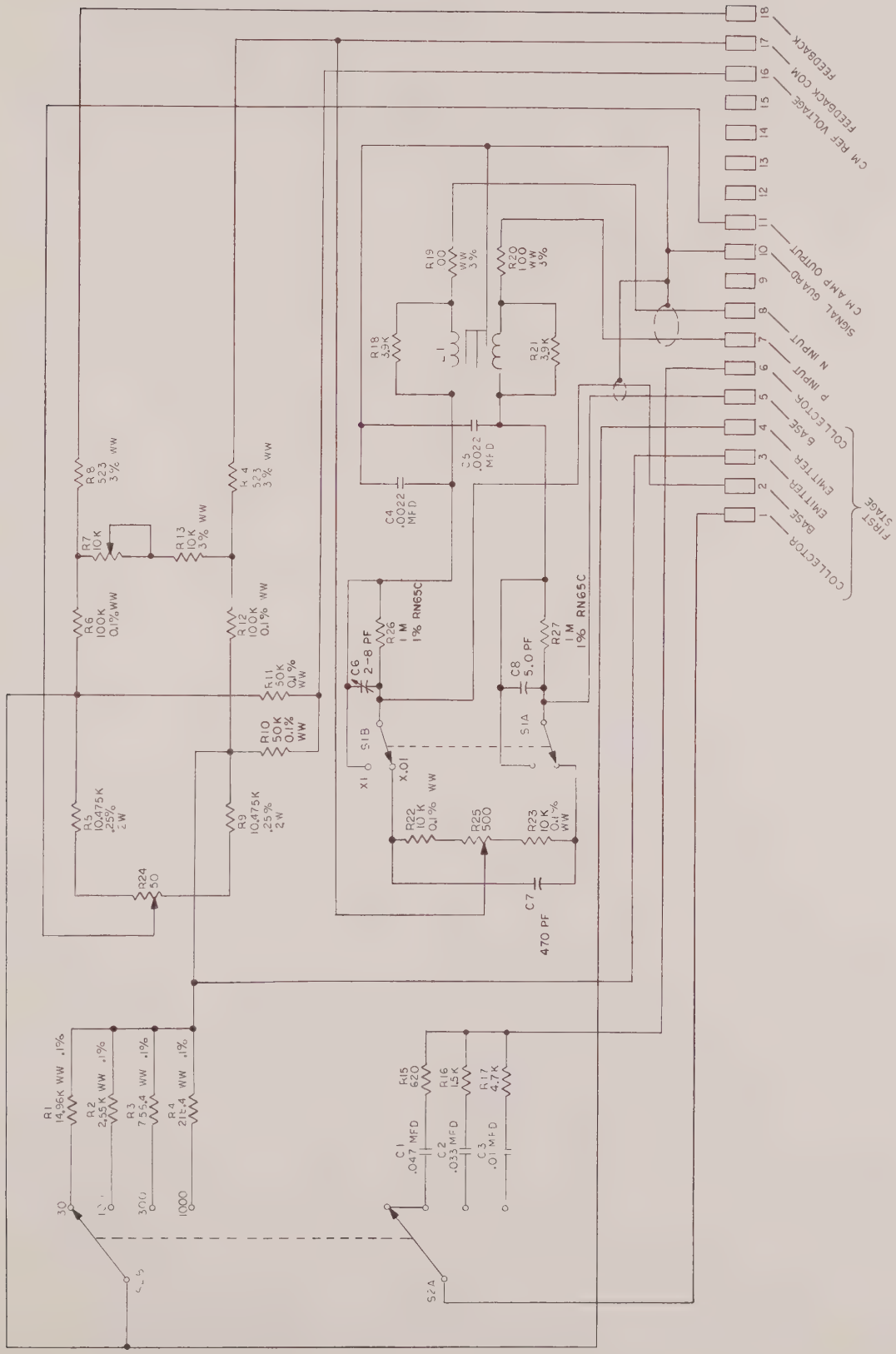


Attenuator, Option F-1, Schematic Diagram

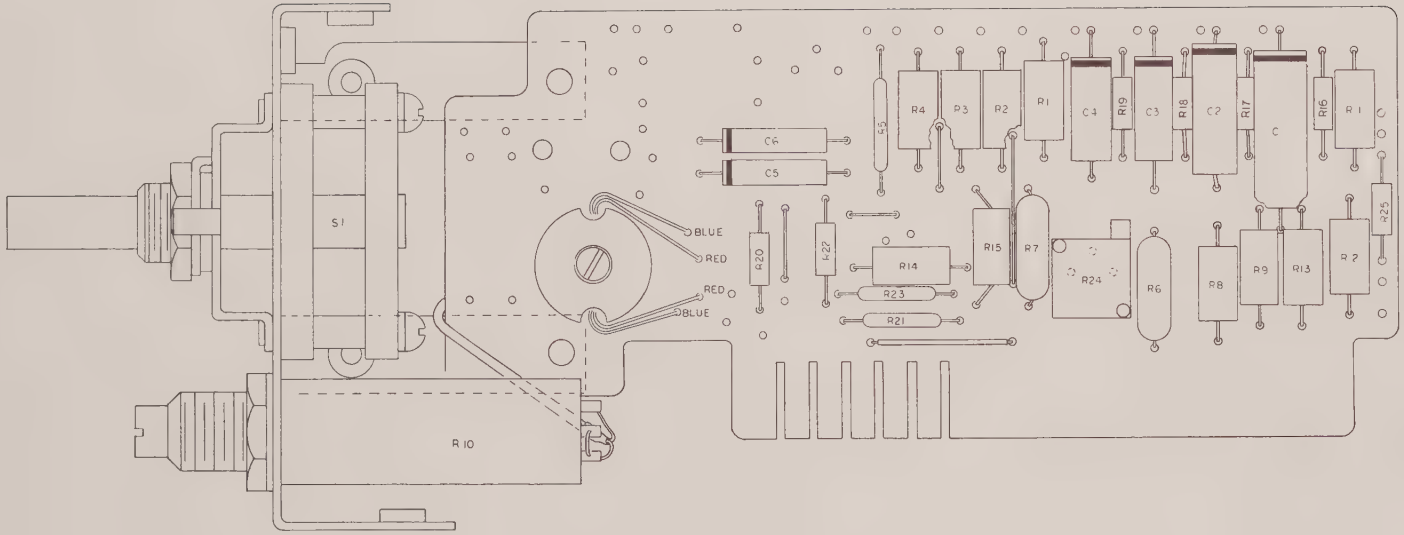


S1-2	29	P/N 600122
L1	27	P/N 400315
C8	18A	50 PF
C7	18B	470 Pf
C6	22A	2-8 PF TRIM
C5	21	.0022 MF
C4	21	.0027 MF
C3	19	.01 MF
C2	20	.033 MF
C1	22	.047 MF
R27	12	1M 1% FILM
R26	2	1M 1% FILM
R25	17A	500Ω POT.
R24	17	50 Ω, POT.
R23	13	10 K, 1% WW
R22	13	10 K, 1% WW
R21	3	3.4 K, 1/4 W, 5%
R20	8	100Ω, 3% WW
R19	8	100Ω, 3% WW
R18	3	3.9K, 1/4W, 5%
R17	3A	4.7K,
R16	1	1.5 K,
R15	4	620Ω, 1/4 W, 5%
R14	16	523Ω, 3% WW
R13	15	10 K, 3% WW
R12	6	100K, 1% WW
R11	5	50 K, 1% WW
R10	5	50 K, 1% WW
R9	7	10.47K, 25% WW
R8	16	523Ω, 3% WW
R7	18	10K POT.
R6	6	100K, 1% WW
R5	7	10.47K, 25% WW
R4	14	218.4Ω, 1% WW
R3	11	756.4Ω, 1% WW
R2	10	2.55 K, 1% WW
R1	9	14.96K, 1% WW
REF DES	B/M 15,M	VALUE

Attenuator, Option F-2, Component Location Guide

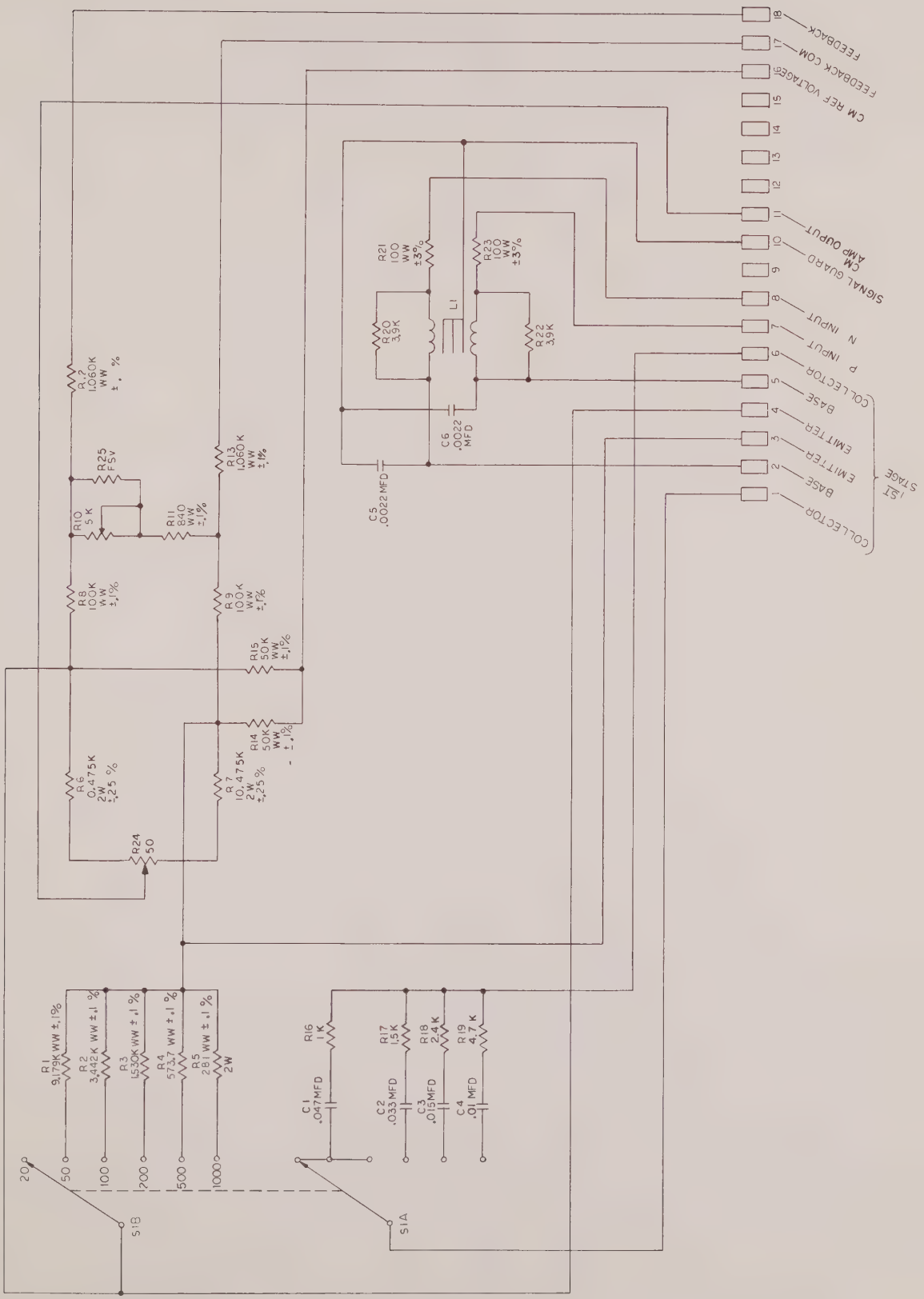


Attenuator, Option F-2, Schematic Diagram

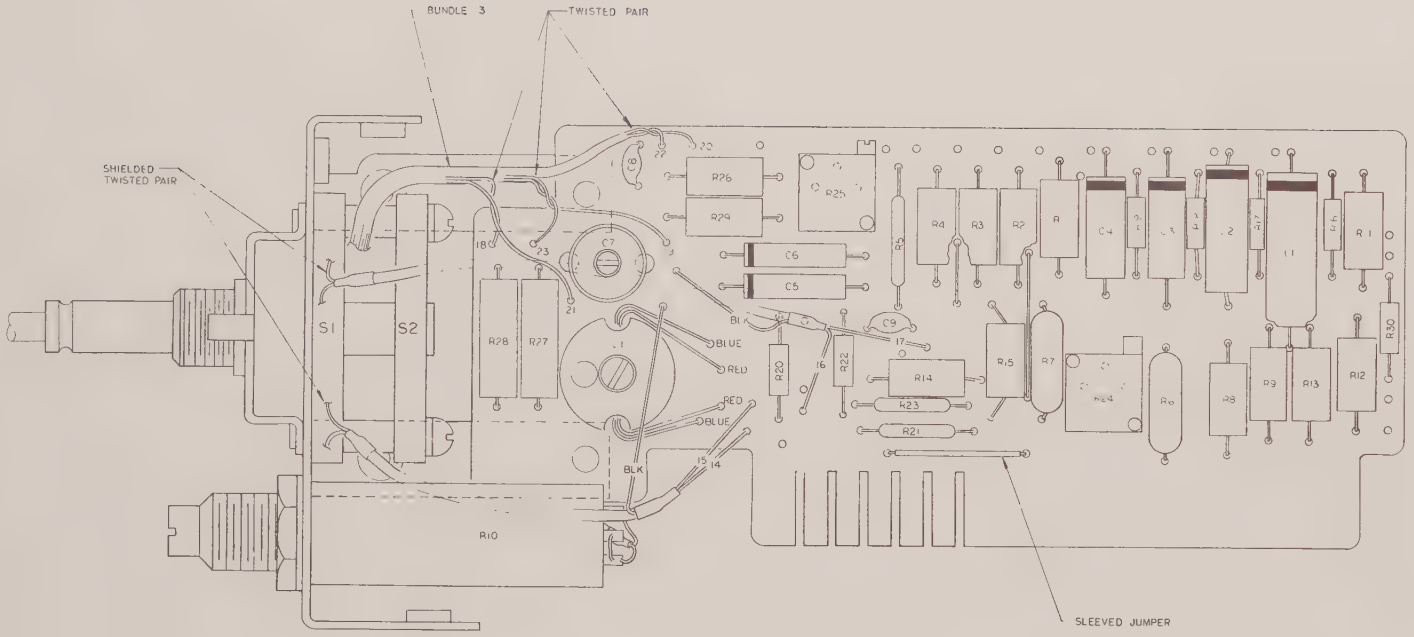


REF DES	ITEM	VALUE
S1	29	P N 600062
L1	26	P N 400315
C6	22	.0022 MF
C5	22	.0022 MF
C4	19	.01 MF
C3	20	.015 MF
C2	21	.033MF
C1	23	.047 MF
R25	–	FSV
R24	8	50 Ω POT.
R23	15	100 Ω 3%WW
R22	4	3.9K
R21	15	100 Ω 3%WW
R20	4	3.9K
R19	4a	4.7 K
R18	2a	2.4 K
R17	.	1.5K
R16	0	1 K
R15	6	50K .1%WW
R14	6	50K " "
R13	13	1.060K " "
R12	13	1.060K " "
R11	14	840 Ω .1% WW
R10	17	5K POT.
R9	7	100K .1%WW
R8	7	100K .1% "
R7	8	10.47K .1%
R6	8	10.47K .1%
R5	16	281.0 Ω .1%
R4	9	573.7 Ω "
R3	10	1.530K "
R2	11	3.442K " "
R1	12	9.179K .1% WW

Attenuator, Option V-1, Component Location Guide

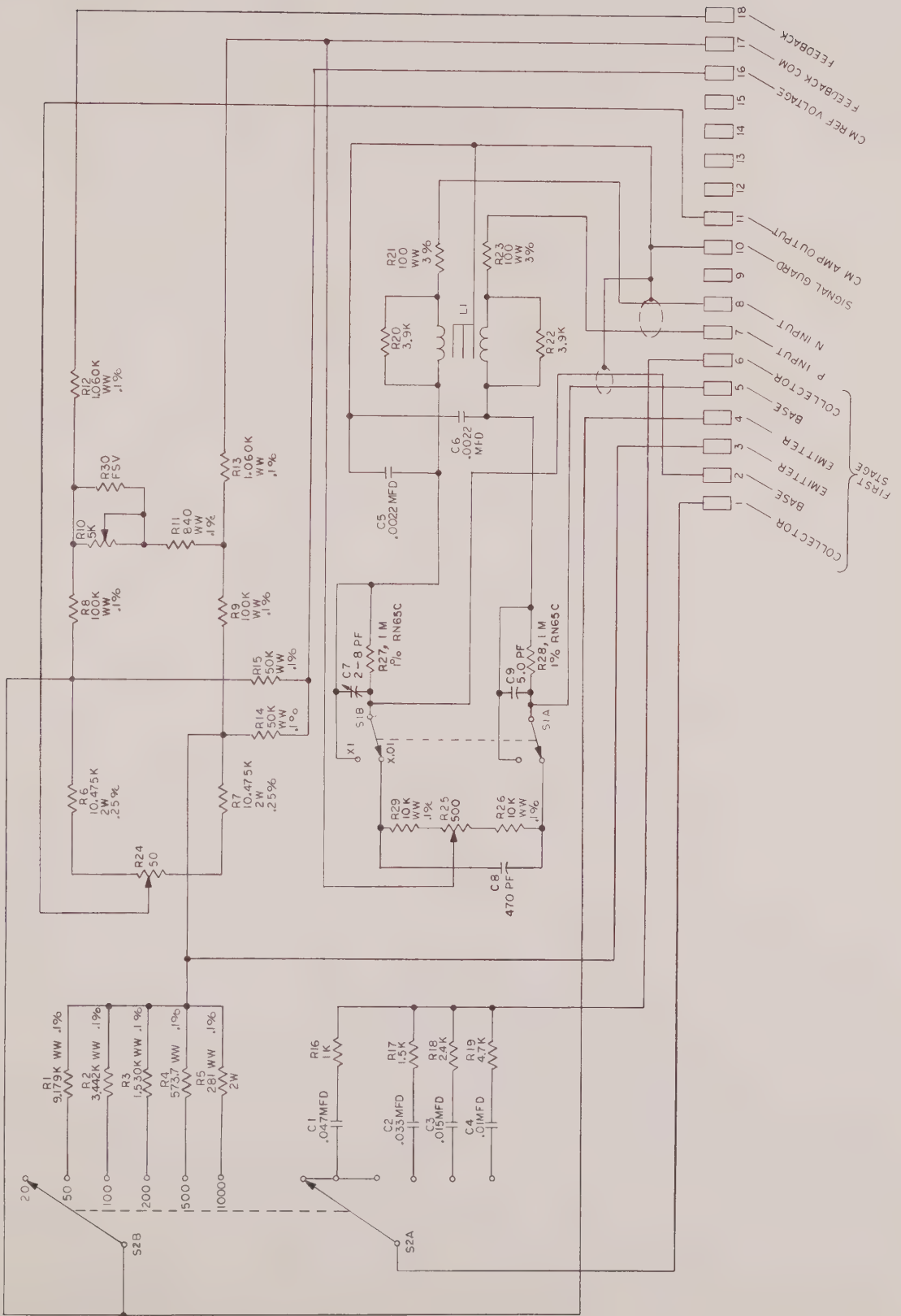


Attenuator, Option V-1, Schematic Diagram



S1-2	32	P/N 600097
J1	29	P/N 450315
C9	20C	5 PF
C8	20B	470 PF
C7	25A	2-8 PF TRIM.
C6	24	.0022 MF
C5	24	.0022 MF
C4	21	.01 MF
C3	22	.015 MF
C2	23	.033 MF
C1	25	.047 MF
R30	—	FSV
R29	17	0 K, 1% WW
R28	16	1 M, 1%
R27	16	1 M, 1%
R26	17	10 K, .1% WW
R25	20A	500 Ω, POT
R24	20	50 Ω, POT
R23	15	100 Ω, 3% WW
R22	4	3.9 K, 1/4 W, 5%
R21	15	100 Ω, 3% WW
R20	4	3.9 K, 1/4 W, 5%
R19	4A	4.7 K,
R18	2A	2.1 K,
R17	1	1.5 K,
R16	0	1.0 K, 1/4 W, 5%
R15	6	50 K, 1% WW
R14	6	50 K,
R13	13	1.060 K,
R12	13	1.060 K,
R11	14	840 Ω, 1% WW
R10	19	5 K POT.
R9	7	100 K, .1% WW
R8	7	100 K, .1%
R7	8	10.47 K, 25%
R6	8	10.47 K, 25%
R5	18	281.0 Ω, .1%
R4	9	573.7 Ω,
R3	10	1.530 K,
R2	11	3.442 K,
R1	12	9.179 K, 1% WW
REF DES	B/M ITEM	VALUE

Attenuator, Option V-2, Component Location Guide



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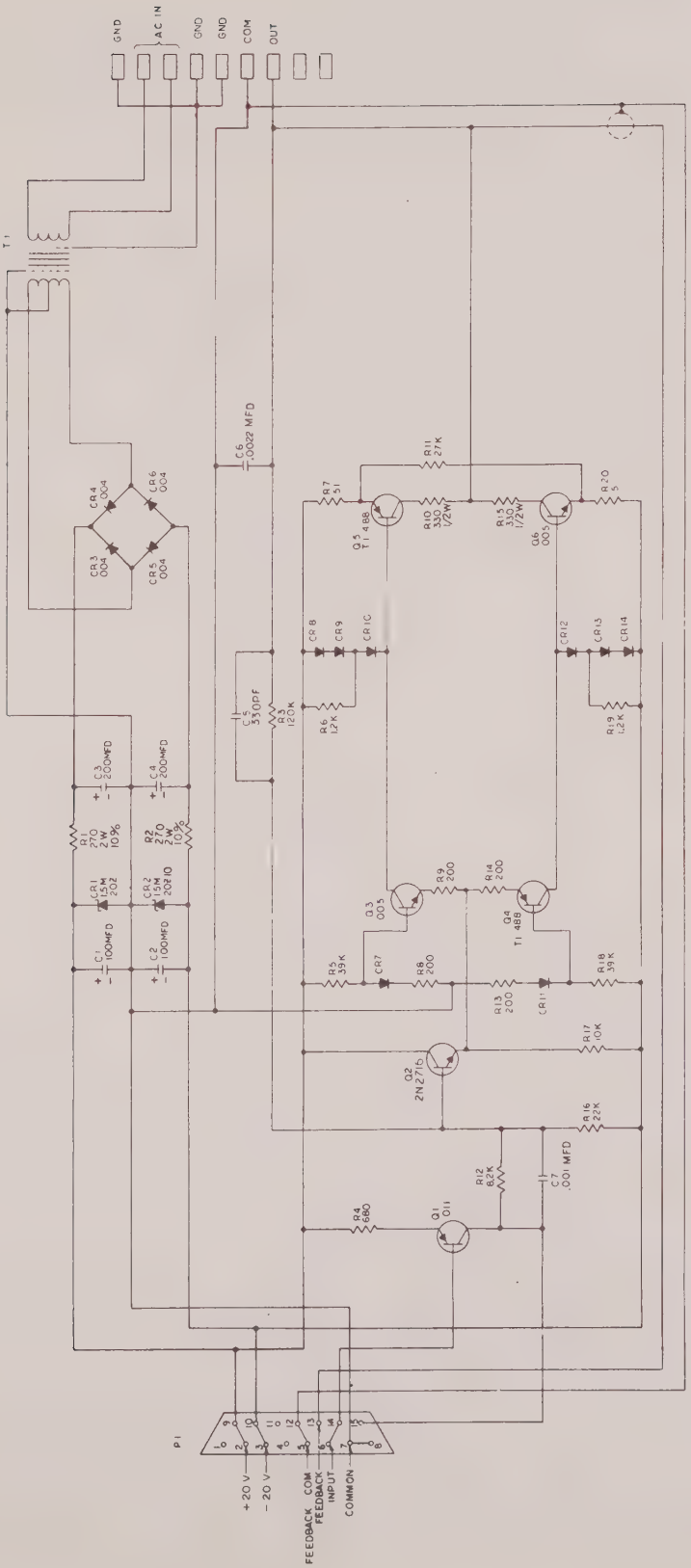
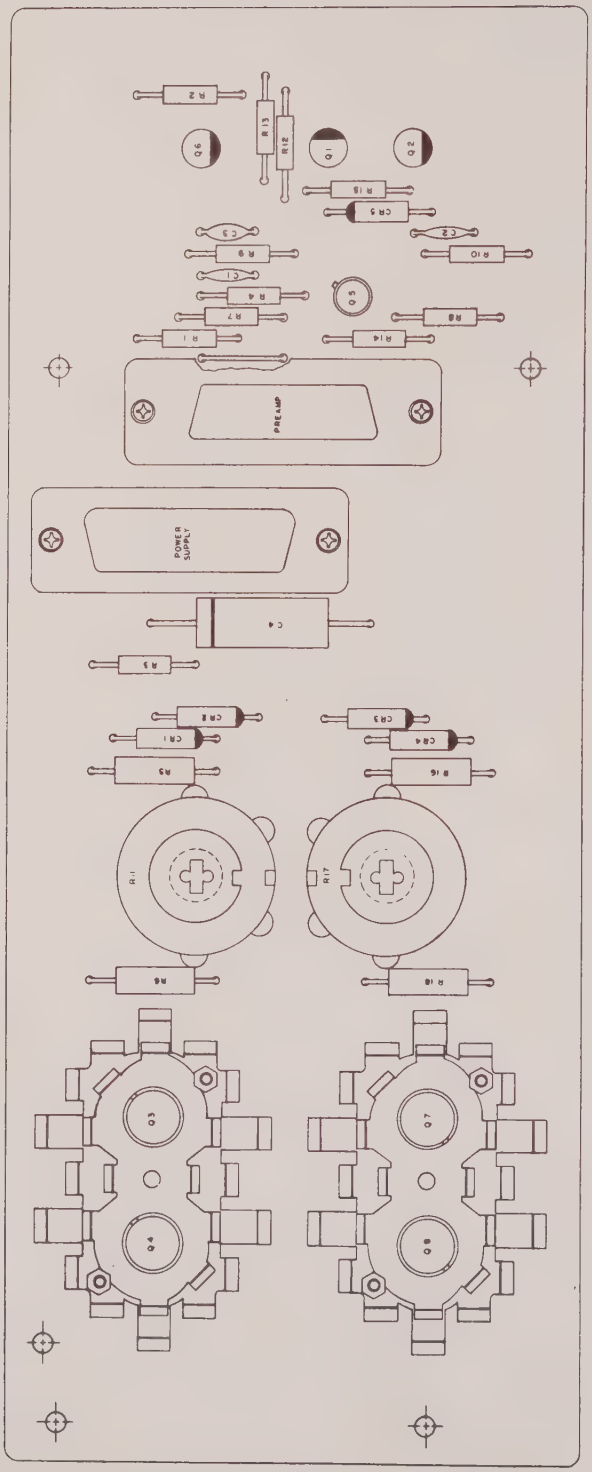
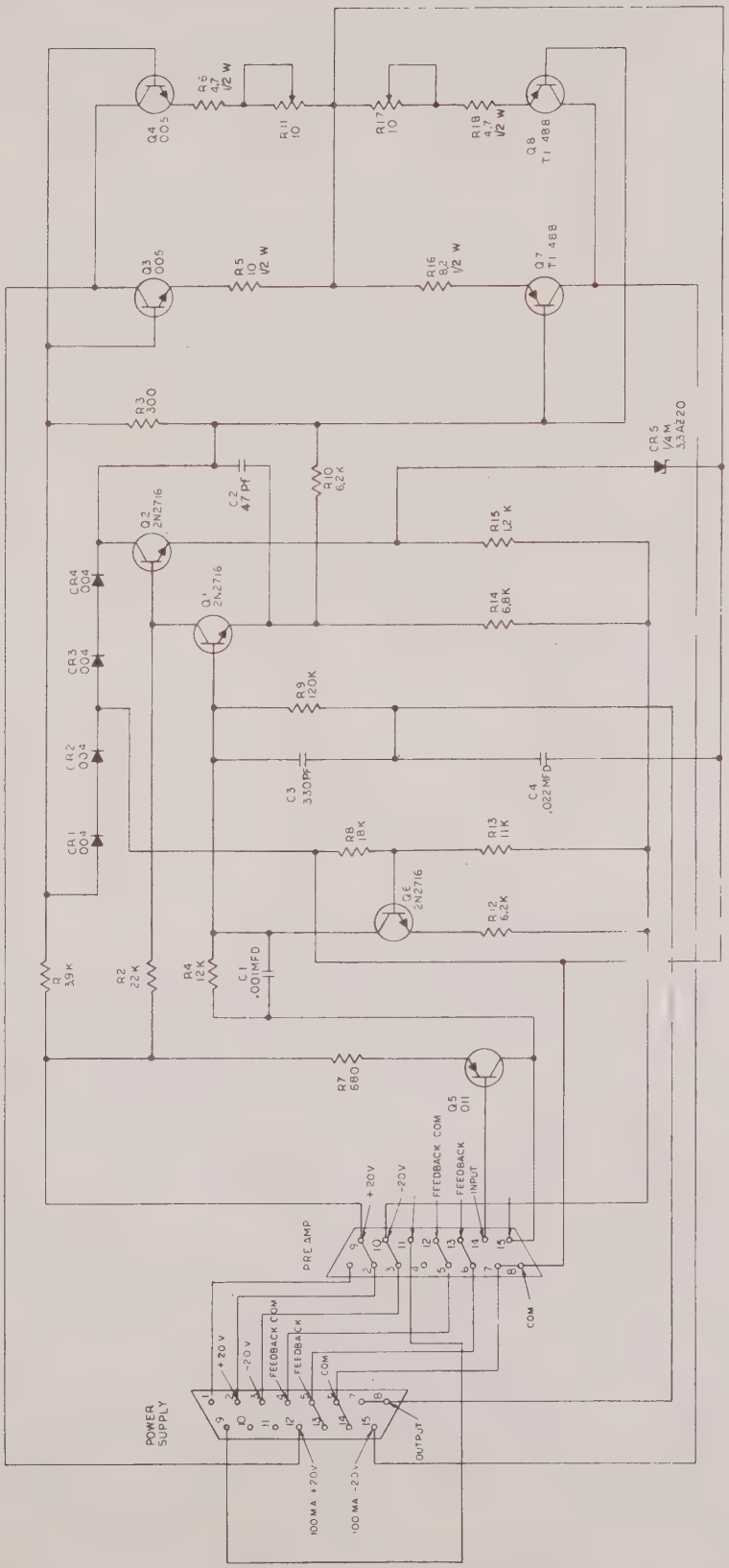


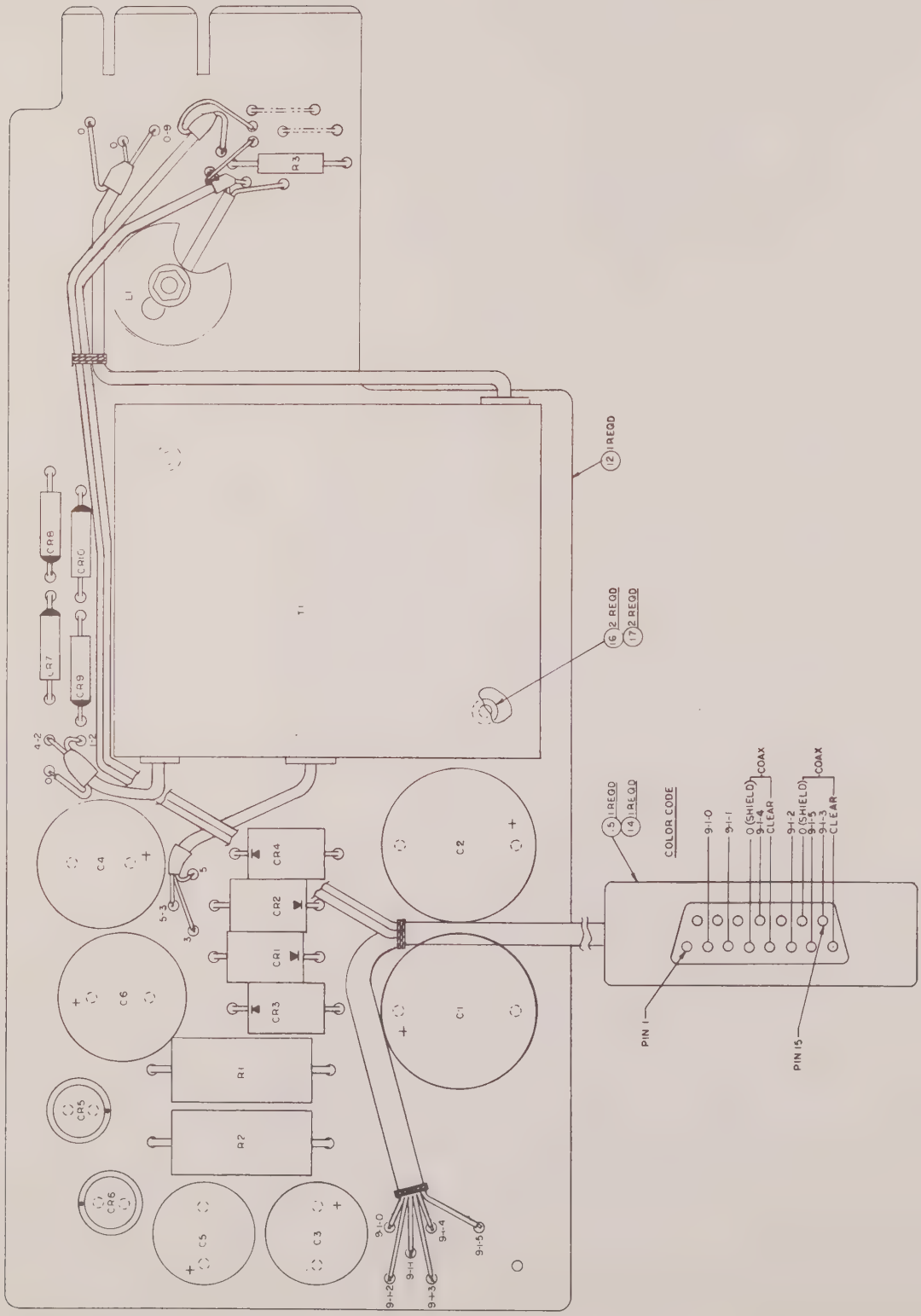
Output Amplifier & Power Supply Schematic



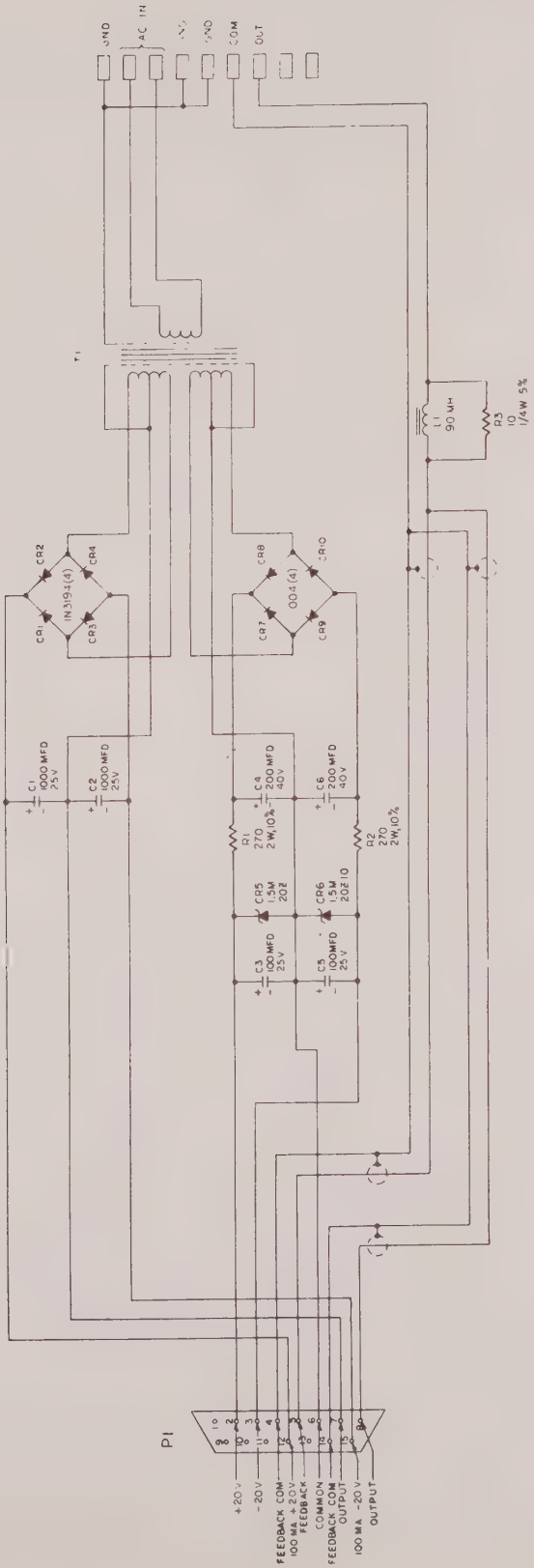
Output Amplifier - Component Location Guide



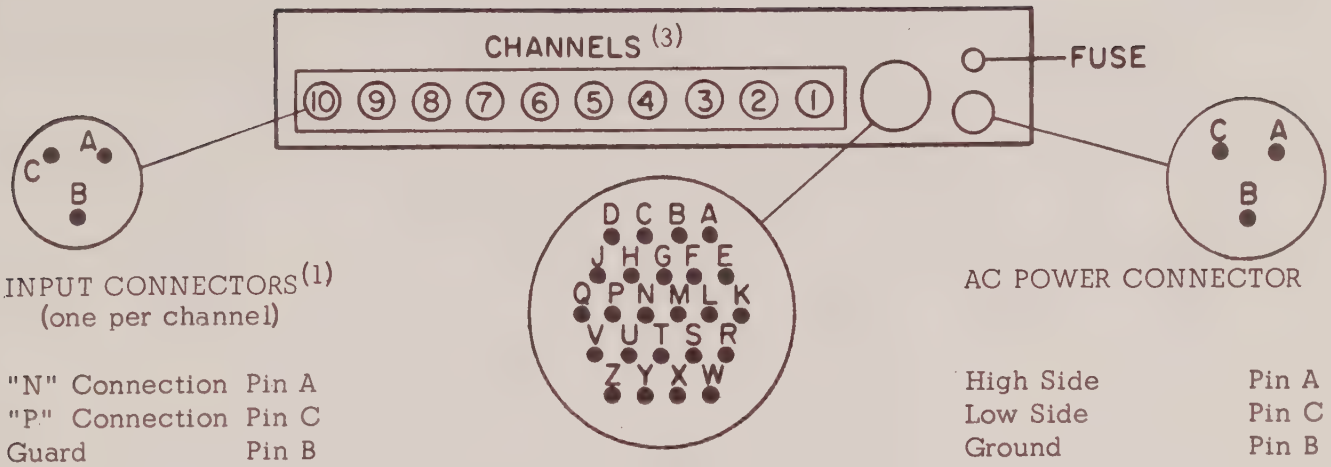
Output Amplifier Schematic



Power Supply - Component Location Guide



Power Supply Schematic



INPUT CONNECTORS (1)
(one per channel)

"N" Connection	Pin A
"P" Connection	Pin C
Guard	Pin B

AC POWER CONNECTOR

High Side	Pin A
Low Side	Pin C
Ground	Pin B

OUTPUT CONNECTOR (2)

Channel	Output	Output Common
1	Pin A	Pin E
2	Pin B	Pin F
3	Pin C	Pin G
4	Pin D	Pin H
5	Pin J	Pin Q
(4) 6	Pin P	Pin V
(4) 7	Pin N	Pin U
(4) 8	Pin M	Pin T
(4) 9	Pin L	Pin S
(4) 10	Pin K	Pin R

Chassis Ground Pin Z

NOTES:

(1) Input leads should be two-conductors enclosed in an insulated shielded wire. Shield is soldered to Guard Pin connection. For optimum performance, use low thermal solder. See Page 5.2 paragraph one for significance of "N" and "P" connections.

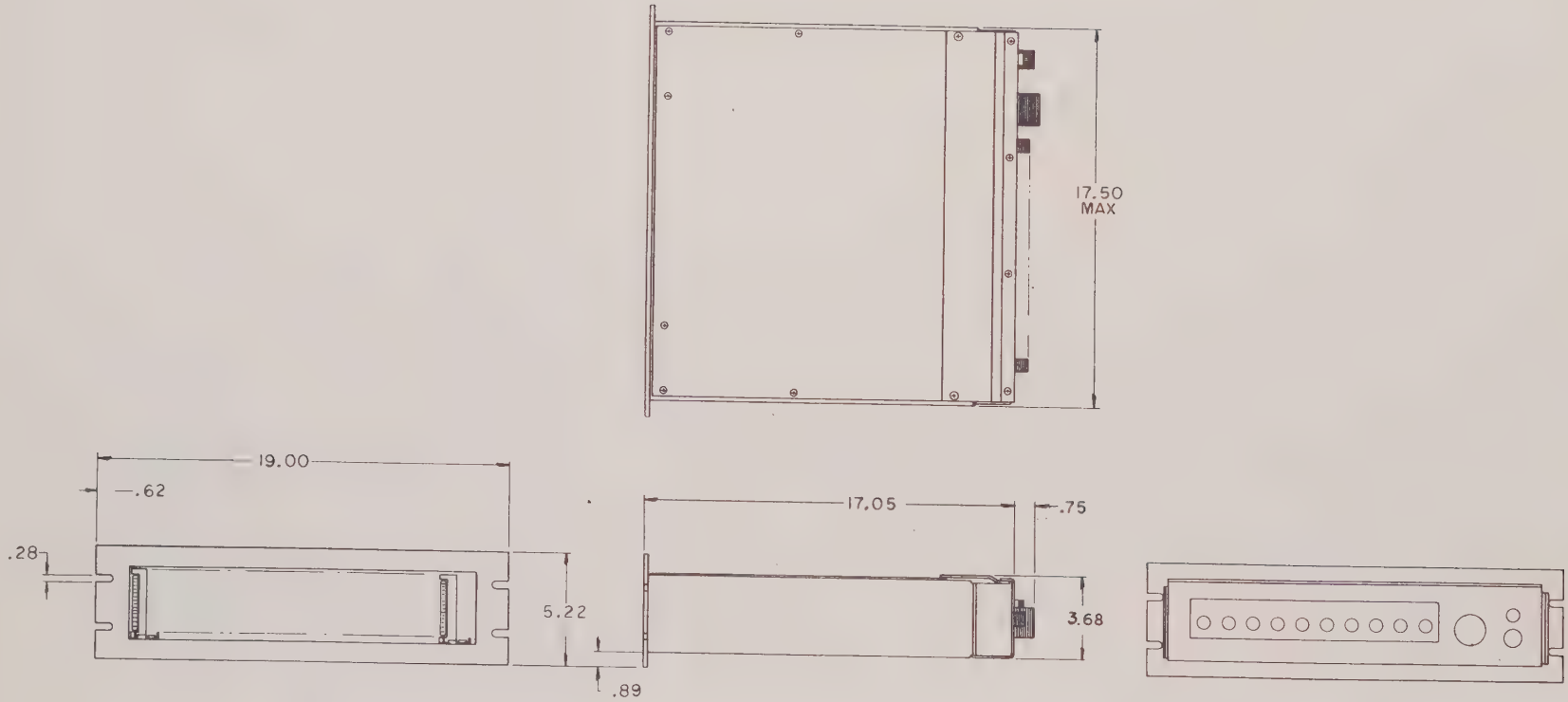
(2) Single-conductor shielded wire is recommended for output leads. Solder shield to Output Common pin. Chassis Ground should be tied to enclosure or rack frame.

(3) Viewing enclosure from the front, amplifiers are numbered from left to right.

(4) Applicable to Model 3010-2 only.

(5) Models 3005-1 and 3010-1 are hard wired to printed circuit connectors at the rear of each amplifier. See Page 9.21 for connectors.

	Mating Connector & Clamps	Dana Part Number
INPUT	3106 A-10 Sl-3S A105-A115	601561
(5 or 10 sets required)	3057-4A-A105 w/Bush	601474
OUTPUT	3106 A-24-28P-639	601563
(1 set required)	3057-16A-639 w/Bush	601564
AC POWER	3106 B-14S-7S-639	601640
(1 set required)	3057-6A-639 w/Bush	601639



Outline Dimensional Drawing, Series 3000 Enclosures

PARTS LIST FOR NORMAL MODE AMPLIFIER
(P/N 400229)

Circuit Designator	Description	Dana P/N
R- 01	Resistor, Carbon, 220 ohm, 1/4W, 5%	000221
R- 02	Resistor, Wirewound, 3.75K, 1%, 1W	020104
R- 03	Resistor, Metal Film, FSV	--
R- 05	Resistor, Metal Film, 4.99K, 1%, RN60B	010020
R- 06	Resistor, Carbon, 10K, 1/4W , 5%	000103
R- 07	Resistor, Carbon, 12K, 1/4W, 5%	000123
R- 08	Resistor, Carbon, 5.1K, 1/4W, 5%	000512
R- 09	Resistor, Metal Film, FSV	--
R- 10	Resistor, Carbon, 10K, 1%, RN65C	010110
R- 11	Resistor, Carbon, 39K,1/4W, 5%	000393
R- 12	Resistor, Carbon, 39K, 1/4W, 5%	000393
R- 13	Resistor, Metal Film, 4.99K, 1%, RN60B	010020
R- 14	Potentiometer, 500 ohm, Techno Type 40	040012
R- 15	Resistor, Carbon, 15K, 1/4W, 5%	000153
R- 16	Resistor, Carbon, 15K, 1/4W, 5%	000153
R- 17	Potentiometer, 20K, Techno Type 40	040011
R- 18	Potentiometer, 20K, Techno Type 40	040011
R- 19	Resistor, FSV	--
R- 20	Resistor, FSV	--
R- 21	Resistor, Carbon, 4.99M, 1%, RN20X	011178
R- 22	Resistor, Carbon, 4.99M, 1%, RN20X	011178
R- 23	Resistor, Carbon, 1/4W, 7.5K, 5%	000752
R- 24	Resistor, Wirewound, FSV	--
R- 25	Resistor, Wirewound, FSV	--
R- 26	Resistor, Metal Film, 4.99K, 1%, RN60B	010020
R- 27	Resistor, Metal Film, 20K, 1%, RN60B	010059
R- 28	Resistor, Metal Film, 6.19K, 1%, RN60B	010130
R- 29	Resistor, Metal Film, FSV	--
R- 30	Resistor, Metal Film, 30.1K, 1%, RN60B	010019
R- 31	Resistor, Metal Film, 20K, 1%, RN60B	010059
R- 32	Resistor, Carbon, 1/4W, 200K, 5%	000204
R- 33	Resistor, Carbon, 1/4W, 12K, 5%	000123
R- 34	Resistor, Carbon, 1/4W, 100K, 5%	000104
C- 01	Capacitor, Mylar, .01 mfd	121088
C- 03	Capacitor, Ceramic Disc, 10 pf	100006
C- 04	Capacitor, Ceramic Disc, 10 pf	100006
C- 05	Capacitor, Mylar, .0047 mfd	121146
C- 06	Capacitor, Ceramic Disc, .001 mfd	101174
C- 07	Capacitor, Electrolytic, 10 mfd, 25V	111262
C- 08	Capacitor, Ceramic Trimmer, 2-8 pf	130004
C- 09	Capacitor, Ceramic Disc, 10 pf	100006
C- 10	Capacitor, Ceramic Disc, 470 pf	101641

NORMAL MODE AMPLIFIER

Circuit Designator	Description	Dana P/N
CR- 01	Diode, Zener, 4AZ10	221177
CR- 02	Diode, 1N662	211083
CR- 03	Diode, 1N662	211083
CR- 04	Diode, 1N662	211083
CR- 05	Diode, 1N662	211083
CR- 06	Diode, 1N662	211083
CR- 07	Diode, 1N662	211083
CR- 08	Diode, 1N662	211083
CR- 09	Diode, Zener, 4AZ10	221177
Q- 01	Transistor, 008	200001
Q- 02	Transistor, 2N2716	200005
Q- 03	Transistor, 2N2716	200005
Q- 04	Transistor, FSV	--
Q- 05	Transistor, FSV	--
Q- 06	Transistor, 2N2716	200005
Q- 07	Transistor, 005	201085
Q- 08	Transistor, 2N2716	200005

PARTS LIST FOR COMMON MODE AMPLIFIER
(P/N 400230)

Circuit Designator	Description	Dana P/N
R-1	Resistor, Carbon, 1/4W, 5%, 10K	000103
R-2	Resistor, Carbon, 1/4W, 5%, 10K	000103
R-3	Resistor, Carbon, 1/4W, 5% 15K	000153
R-4	Resistor, Carbon, 1/4W, 5% 220 ohm	000221
R-5	Resistor, Carbon, 1/4W, 5% 1.5K	000152
R-6	Resistor, MMF , 1%, 499 ohm, RN60B	010027
R-7	Resistor, MMF , 1%, 1.4K, RN60B	010008
R-8	Resistor, MMF , 1%, 2.61K, RN60B	011334
R-9	Resistor, Carbon, 1/4W, 5%, 82K	000823
R-10	Resistor, Carbon, 1/4W, 5%, 2.2K	000222
R-11	Resistor, Carbon, 1.4W, 5%, 22 ohm	000220
C-1	Capacitor, Mylar,.033 uf	121091
C-2	Capacitor, Ceramic Disc, 470 pf	101641
C-3	Capacitor, Mylar, .022 uf	121468
CR-1	Diode, 1N662	211083
CR-3	Diode, 004	211126
CR-4	Diode, 004	211126
Q-1	Transistor, 2N2716	200005
Q-2	Transistor, 2N2716	200005
Q-3	Transistor, 2N2716	200005
Q-4	Transistor, 2N2716	200005
Q-5	Transistor, 2N2716	200005
Q-6	Transistor, TI488	201143
Q-7	Transistor, 005	201085

PARTS LIST FOR ATTENUATOR, OPTION F-1
(P/N 400163)

Circuit Designator	Description	Dana P/N
R-1	Resistor, Wirewound, 1496K, .1%	020093
R-2	Resistor, Wirewound, 2.55K .1%	020094
R-3	Resistor, Wirewound, 756.4 ohm, .1%	020095
R-4	Resistor, Wirewound, 218.4 ohm, .1%	020129
R-5	Resistor, Wirewound, 10.47K, .25%	020108
R-6	Resistor, Wirewound, 100K, .1%	020079
R-7	Potentiometer, 10K	041158
R-8	Resistor, Wirewound, 523 ohm, 3%	021155
R-9	Resistor, Wirewound, 10.47K, .25%, 2W	020108
R-10	Resistor, Wirewound, 50K, .1%	020078
R-11	Resistor, Wirewound, 50K, .1%	020078
R-12	Resistor, Wirewound, 100K, .1%	020079
R-13	Resistor, Wirewound, 10K, 3%	021154
R-14	Resistor, Wirewound, 523 Ohm, 3%	021155
R-15	Resistor, Carbon, 620 Ohm, 1/4W, 5%	000621
R-16	Resistor, Carbon, 1.5K, 1/4W, 5%	000152
R-17	Resistor, Carbon, 4.7K, 1/4W, 5%	000472
R-18	Resistor, Carbon, 3.9K, 1/4W, 5%	000392
R-19	Resistor, Wirewound, 100 ohm, 3%	020106
R-20	Resistor, Wirewound, 100 ohm, 3%	020106
R-21	Resistor, Carbon, 3.9K, 1/4W, 5%	000392
R-22	Potentiometer, 50 ohm, Techno 25	040019
C-1	Capacitor, Mylar, .047 mfd	121093
C-2	Capacitor, Mylar, .033 mfd	121091
C-3	Capacitor, Mylar, .0022 mfd	121092
C-5	Capacitor, Mylar, .0022 mfd	121092
L-1	Choke - RF Filter	400315
S1	Switch- Rotary, 2-6 Pos, CTS Special w/Lock, Tab and Nut	600062

MISCELLANEOUS

Knob - Silkscreened, Option F-1	450336
Knob - Raytheon #70-3NP-2 G	920068

PARTS LIST FOR ATTENUATOR, OPTION F-2
(P/N 400239)

Circuit Designator	Description	Dana P/N
R-1	Resistor, Wirewound, .1%, 14.96K	020093
R-2	Resistor, Wirewound, .1%, 2.55K	020094
R-3	Resistor, Wirewound, .1%, 756.4 ohm	020095
R-4	Resistor, Wirewound, .1%, 218.4 ohm	020099
R-5	Resistor, Wirewound, .25%, 10.47K, 2W	020108
R-6	Resistor, Wirewound, .1%, 100K	020079
R-7	Potentiometer, 10K	041158
R-8	Resistor, Wirewound, 3%, 523 ohm	021155
R-9	Resistor, Wirewound, .25%, 10.47, 2W	020108
R-11	Resistor, Wirewound, .1%, 50K	020078
R-12	Resistor, Wirewound, .1%, 100K	020079
R-13	Resistor, Wirewound, 3%, 10K	021154
R-14	Resistor, Wirewound, 3%, 523 ohm	021155
R-15	Resistor, Carbon, 1/4W, 620 ohm, 5%	000621
R-16	Resistor, Carbon, 1/4W, 1.5K, 5%	000152
R-17	Resistor, Carbon, 1/4W, 4.7K, 5%	000472
R-18	Resistor, Carbon, 1/4W, 3.9K, 5%	000392
R-19	Resistor, Wirewound, 3%, 100 ohm	020106
R-20	Resistor, Wirewound, 3%, 100 ohm	020106
R-21	Resistor, Carbon, 1/4W, 3.9K, 5%	000392
R-22	Resistor, Wirewound, 10K, .1%	020097
R-23	Resistor, Wirewound, 10K, .1%	020097
R-24	Potentiometer, 50 ohm, Techno Mod. 25	040019
R-25	Potentiometer, 500 ohm, Techno Mod. 25	040031
R-26	Resistor, Metal Film, 1%, 1M, RN65C	010111
R-27	Resistor, Metal Film, 1%, 1M, RN65C	010111
C-1	Capacitor, Mylar, .047 mfd	121093
C-2	Capacitor, Mylar, .033 mfd	121091
C-3	Capacitor, Mylar, .01 mfd	121088
C-4	Capacitor, Mylar, .0022 mfd	121092
C-5	Capacitor, Mylar, .0022 mfd	121092
C-6	Capacitor, 2-8 pf, Range, Trimmer	130004
C-7	Capacitor, 470 pf, Ceramic Disc	101641
C-8	Capacitor, 5.0 pf, Ceramic Disc	100004
L-1	Choke - RF Filter	400315
S1	Switch - Concentric Rotary, CTS #53459	600122
Miscellaneous		
	Knob - Concentric X.01 S1	450147
	Bracket - Attenuator	450175
	Knob - Silkscreened, Option F-2	450337
	Knob - Raytheon, 1/8" Shaft	920069

PARTS LIST FOR ATTENUATOR, OPTION V-1
(P/N 400171)

Circuit Designator	Description	Dana P/N
R-1	Resistor, Wirewound, .1%, 9.179K	020084
R-2	Resistor, Wirewound, .1%, 3.442K	020083
R-3	Resistor, Wirewound, .1%, 1.530K	020082
R-4	Resistor, Wirewound, .1%, 573.7 ohm	020081
R-5	Resistor, Wirewound, .1%, 281.0 ohm	020101
R-6	Resistor, Wirewound, ±.1%, 10.47K, 2W	020105
R-7	Resistor, Wirewound, ±.1%, 10.47K, 2W	020105
R-8	Resistor, Wirewound, .1%, 100K	020079
R-9	Resistor, Wirewound, .1%, 100K	020079
R-10	Potentiometer, 5K, Type 5000	040016
R-11	Resistor, Wirewound, .1%, 840 ohm	020086
R-12	Resistor, Wirewound, .1%, 1.060K	020085
R-13	Resistor, Wirewound, .1%, 1.060K	020085
R-14	Resistor, Wirewound, .1%, 50K	020078
R-15	Resistor, Wirewound, .1%, 50K	020078
R-16	Resistor, Carbon, 1/4W, 1K, 5%	000102
R-17	Resistor, Carbon, 1/4W, 1.5K, 5%	000152
R-18	Resistor, Carbon, 1/4W, 2.4K, 5%	000242
R-19	Resistor, Carbon, 1/4W, 4.7K, 5%	000472
R-20	Resistor, Carbon, 1/4W, 3.9K, 5%	000392
R-21	Resistor, Wirewound, 3%, 100 ohm	020106
R-22	Resistor, Carbon, 1/4W, 3.9K	000392
R-23	Resistor, Wirewound, 3%, 100 ohm	020106
R-24	Potentiometer, 50 ohm, Techno 25	040019
C-1	Capacitor, Mylar, .047 mfd	121093
C-2	Capacitor, Mylar, .033 mfd	121091
C-3	Capacitor, Mylar, .015 mfd	121090
C-4	Capacitor, Mylar, .01 mfd	121088
C-5	Capacitor, Mylar, .002 mfd	121092
C-6	Capacitor, Mylar, .002 mfd	121092
L-1	Choke, RF Filter	
S1	Switch, Rotary, 2-6 Pos, CTS Special w/Lock, Tab and Nut	600062
Miscellaneous		
	Bracket - Attenuator	450253
	Knob - Silkscreened, Option V-1	450339
	Knob - Raytheon, #70-3NP-2G	920068
	Grommet - Nylon, #4-40 I.D.	610097

PARTS LIST FOR ATTENUATOR, OPTION V-2
(P/N 400240)

Circuit Designator	Description	Dana P/N
R-1	Resistor, Wirewound, 9.179K, .1%	020084
R-2	Resistor, Wirewound, 3.442K, .1%	020083
R-3	Resistor, Wirewound, 1.530K, .1%	020082
R-4	Resistor, Wirewound, 573.7 ohm, .1%	020081
R-5	Resistor, Wirewound, 281 ohm, .1%, 2W	020101
R-6	Resistor, Wirewound, 10.47K, ±.1%, 2W	020105
R-7	Resistor, Wirewound, 10.47K, ±.1%, 2W	020105
R-8	Resistor, Wirewound, 100K, .1%	020079
R-9	Resistor, Wirewound, 100K, .1%	020079
R-10	Potentiometer, 5K, IRC Type 5000	040016
R-11	Resistor, Wirewound, 840 ohm, .1%	020086
R-12	Resistor, Wirewound, 1.060K, .1%	020085
R-13	Resistor, Wirewound, 1.060K, .1%	020085
R-14	Resistor, Wirewound, 50K, .1%	020078
R-15	Resistor, Wirewound, 50K, .1%	020078
R-16	Resistor, Carbon, 1K, 1/4W, 5%	000102
R-17	Resistor, Carbon, 1.5K, 1/4W, 5%	000152
R-18	Resistor, Carbon, 2.4K, 1/4W, 5%	000242
R-19	Resistor, Carbon,4.7K, 1/4W, 5%	000472
R-20	Resistor, Carbon, 3.9K, 1/4W, 5%	000392
R-21	Resistor, Wirewound, 100 ohm, 3%	020106
R-22	Resistor, Carbon, 3.9K, 1/4W, 5%	000392
R-23	Resistor, Wirewound, 100 Ohm, 3%	020106
R-24	Potentiometer, 50 ohm, Techno Mod. 25	040019
R-25	Potentiometer, 500 ohm, Techno 25	040031
R-26	Resistor, Wirewound, 10K, .1%	020097
R-27	Resistor, Metal Film, 1M, 1%, RN65C	010111
R-28	Resistor, Metal Film, 1M, 1% RN65C	010111
R-29	Resistor, 10K, .1%, Wirewound	020097
R-30	Resistor, FSV	--
C-1	Capacitor, Mylar, .047 mfd	121093
C-2	Capacitor, Mylar, .033 mfd	121091
C-3	Capacitor, Mylar, .015 mfd	121090
C-4	Capacitor, Mylar, .01 mfd	121088
C-5	Capacitor, Mylar, .0022 mfd	121092
C-6	Capacitor, Mylar, .0022 mfd	121092
C-7	Capacitor, 2-8 pf, Trimmer	130004
C-8	Capacitor, 476 pf, Ceramic Disc	101641
C-9	Capacitor, 5 pf, Ceramic Disc	100004
L-1	Choke, R. F. Filter	400315
S1	Switch, Concentric Rotary, CTS #53460	600097
Miscellaneous:	Knob - Concentric X.01 X1	450147
	Knob - Silkscreened, Option V-2	450340
	Knob - Raytheon, 1/8" Shaft	920069
	Bracket - Attenuator	450253
	Grommet - Mylon 1/4 I.D.	610097

PARTS LIST FOR OUTPUT AMPLIFIER AND POWER SUPPLY
(P/N 400162)

Circuit Designator	Description	Dana P/N
R-1	Resistor, Carbon, 270 ohm, 10%, 2W	031160
R-2	Resistor, Carbon, 270 ohm, 10%, 2W	031160
R-3	Resistor, Carbon, 120K, 1/4W, 5%	000124
R-4	Resistor, Carbon, 680 ohm, 1/4W, 5%	000681
R-5	Resistor, Carbon, 39K, 1/4W, 5%	000393
R-6	Resistor, Carbon, 1.2K, 1/4W, 5%	000122
R-7	Resistor, Carbon, 51 ohm, 1/4W, 5%	000510
R-8	Resistor, Carbon, 200 ohm, 1/4W, 5%	000201
R-9	Resistor, Carbon, 200 ohm, 1/4W, 5%	000201
R-10	Resistor, Carbon, 330 ohm, 1/2W, 5%	001159
R-11	Resistor, Carbon, 27K, 1/4W, 5%	000273
R-12	Resistor, Carbon, 8.2K, 1/4W, 5%	000822
R-13	Resistor, Carbon, 200 ohm, 1/4W, 5%	000201
R-14	Resistor, Carbon, 200 ohm, 1/4W, 5%	000201
R-15	Resistor, Carbon, 330 ohm, 1/2W, 5%	001159
R-16	Resistor, Carbon, 22K, 1/4W, 5%	000223
R-17	Resistor, Carbon, 10K, 1/4W, 5%	000103
R-18	Resistor, Carbon, 39K, 1/4W, 5%	000393
R-19	Resistor, Carbon, 1.2K, 1/4W, 5%	000122
R-20	Resistor, Carbon, 51 ohm, 1/4W, 5%	000510
C-1	Capacitor, 100 uf, 25V, MEC	110008
C-2	Capacitor, 100 uf, 25V, MEC	110008
C-3	Capacitor, 200 uf, 40V, MEC	110015
C-4	Capacitor, 200 uf, 40V, MEC	110015
C-5	Capacitor, Ceramic Disc, 330 pf	101098
C-6	Capacitor, Mylar, .0022 uf	121092
C-7	Capacitor, Ceramic Disc, .001 uf	101174
T-1	Transformer, Power	301138
Q-1	Transistor, Type 011	200015
Q-2	Transistor, 2N2716	200005
Q-3	Transistor, Type 005	201085
Q-4	Transistor, TI 488	201143
Q-5	Transistor, TI 488	201143
Q-6	Transistor, Type 005	201085
CR-1	Diode, Zener, 1.5M20Z	221142
CR-2	Diode, Zener, 1.5M20AZ10	220005
CR-3	Diode, 004	211126
CR-4	Diode, 004	211126
CR-5	Diode, 004	211126

OUTPUT AMPLIFIER & POWER SUPPLY

Circuit Designator	Description	Dana P/N
CR-6	Diode, 004	211126
CR-7	Diode, 1N662	211083
CR-8	Diode, 1N662	211083
CR-9	Diode, 1N662	211083
CR-10	Diode, 1N662	211083
CR-11	Diode, 1N662	211083
CR-12	Diode, 1N662	211083
CR-13	Diode, 1N662	211083
CR-14	Diode, 1N662	211083

PARTS LIST FOR OUTPUT AMPLIFIER
(P/N 400170)

Circuit Designator	Description	Dana P/N
R-1	Resistor, Carbon, 3.9K, 1/4W, 5%	000392
R-2	Resistor, Carbon, 22K, 1/4W, 5%	000223
R-3	Resistor, Carbon, 300 ohm, 1/4W, 5%	000301
R-4	Resistor, Carbon, 12K, 1/4W, 5%	000123
R-5	Resistor, Carbon, 10 ohm, 1/2W	001472
R-6	Resistor, Carbon, 4.7 ohm, 1/2W	001570
R-7	Resistor, Carbon, 680 ohm, 1/4W	000681
R-8	Resistor, Carbon, 18K, 1/4W, 5%	000183
R-9	Resistor, Carbon, 120K, 1/4W, 5%	000124
R-10	Resistor, Carbon, 6.2K, 1/4W, 5%	000622
R-11	Potentiometer, 10 ohm	041476
R-12	Resistor, Carbon, 6.2K, 1/4W, 5%	000622
R-13	Resistor, Carbon, 11K, 1/4W, 5%	000113
R-14	Resistor, Carbon, 6.8K, 1/4W, 5%	000682
R-15	Resistor, Carbon, 1.2K, 1/4W, 5%	000122
R-16	Resistor, Carbon, 8.2 ohm, 1/2W, 5%	001475
R-17	Potentiometer, 10 ohm	041476
R-18	Resistor, Carbon, 4.7 ohm, 1/2W, 5%	001570
C-1	Capacitor, Ceramic, .001 mfd	101174
C-2	Capacitor, Ceramic, 47 pf	101182
C-3	Capacitor, Ceramic, 330 pf	101098
C-4	Capacitor, Mylar, .022 mfd	121468
Q-1	Transistor, 2N2716	200005
Q-2	Transistor, 2N2716	200005
Q-3	Transistor, Type 005	201085
Q-4	Transistor, Type 005	201085
Q-5	Transistor, Type 011	200015
Q-6	Transistor, 2N2716	200005
Q-7	Transistor, TI488	201143
Q-8	Transistor, TI488	201143
CR-1	Diode, 004	211126
CR-2	Diode, 004	211126
CR-3	Diode, 004	211126
CR-4	Diode, 004	211126
CR-5	Diode, Zener, 3AZ20	221631
CR-6	Diode, 1N662	211083

PARTS LIST FOR POWER SUPPLY
(P/N 400169)

Circuit Designator	Description	Dana P/N
R-1	Resistor, Carbon, 270 ohm, 2W, 10%	031160
R-2	Resistor, Carbon, 270 ohm, 2W, 10%	031160
R-3	Resistor, Carbon, 10 ohm, 1/4W, 5%	000100
C-1	Capacitor, Electrolytic, 100 mfd	110010
C-2	Capacitor, Electrolytic, 100 mfd	110010
C-3	Capacitor, Electrolytic, 100 mfd	110008
C-4	Capacitor, Electrolytic, 200 mfd	110015
C-5	Capacitor, Electrolytic, 100 mfd	110008
C-6	Capacitor, Electrolytic, 200 mfd	110015
CR-1	Diode, 1N3194	211386
CR-2	Diode, 1N3194	211386
CR-3	Diode, 1N3194	211386
CR-4	Diode, 1N3194	211386
CR-5	Diode, Zener, 1.5M20Z	221142
CR-6	Diode, Zener ,1.5M 20AZ10	220005
CR-7	Diode, Type 004	211126
CR-8	Diode, Type 004	211126
CR-9	Diode, Type 004	211126
CR-10	Diode, Type 004	211126
L-1	Output Choke	310008
T-1	Transformer, Power	301369

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